

Effectiveness of Local
Exhaust Ventilation for
Drum Filling Operations

PEI Associates, Inc., Cincinnati, OH

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EFFECTIVENESS OF
LOCAL EXHAUST VENTILATION
FOR DRUM-FILLING OPERATIONS

by

PEI Associates, Inc.
11499 Chester Road
Cincinnati, Ohio 45246

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SECTION 1

INTRODUCTION

1.1 BACKGROUND

The review of Premanufacture Notifications (PMN's) submitted by chemical producers and processors frequently requires that estimates be made of employee exposure to vapors emitted from drum-filling operations. This exposure estimate should take into account the effectiveness of associated local exhaust ventilation (LEV) systems, when their use is indicated by the producer or processor. To date, however, no reliable method is available for estimating the reduction in employee exposure achieved by an LEV system and thus, no "credit" is given when LEV is used.

The purpose of this study was to determine experimentally the effectiveness of LEV systems in capturing vapors generated from drum-filling operations as an example. The experiments consisted of measuring the effectiveness of three LEV systems (a canopy hood, a slot hood, and a lay-on hood) for a simulated drum-filling operation. The intent of the study was to develop a rough order-of-magnitude estimate of the reduction which LEV systems can provide, in particular when such information is needed to assess exposure when little is known about systems which may be in use. Its intent was not to provide a detailed accounting for all of the conditions which might be encountered regarding LEV systems in industry (e.g., cross drafts or the effects of work practices), nor to develop or confirm design criteria for the LEV systems.

1.2 APPROACH

The first step taken towards the goal of this study was the development of a method for simulating emissions from a drum-filling operation. Because of the operational, safety, and health problems associated with filling drums with volatile liquids, drum-filling emissions were simulated by injecting

mixtures of a fluorochlorocarbon gas and air into the bottom of a 55-gallon drum. Previous experimental studies provided information on actual emissions during the filling of a drum with volatile liquids.¹ Data from these studies were used as the basis for setting the rates at which the fluorochlorocarbon gas was fed to the drum.

The second step involved constructing a station in which to test LEV effectiveness. A ventilated enclosure having the dimensions of 8 ft by 8 ft by 16 ft was erected at the National Institute of Occupational Safety and Health (NIOSH) ventilation research facility in Cincinnati, Ohio. This facility contained a large ventilation system into which exhaust air could be drawn from the enclosure and the LEV systems.

The third step involved actual testing to determine the effectiveness of the LEV systems. A 55-gallon drum placed in the middle of the enclosure was fed different concentrations of the fluorochlorocarbon test gas which simulated the emissions from a drum being filled with liquid. The LEV system under study for a particular test was set in place. When the system reached equilibrium, test gas concentration levels were measured with a flame ionization detector (FID) at selected points in the enclosure (including the breathing zone of a mannequin located next to the drum) and in the LEV and enclosure exhaust ducts. The effectiveness of the LEV system was estimated from both the reduction in the test gas concentration at the breathing zone of the mannequin and the percentage of test gas captured by the LEV system.

1.3 CONTENTS

Section 2 presents an evaluation of the different approaches available for simulating drum-filling of liquids. Section 3 presents a detailed discussion of the experimental methods used in this study. It begins with the selection of an approach to drum-filling simulation followed by a detailed description of 1) test-site setup, 2) test procedures, and 3) calculations used to generate the final results. Section 4 includes experimental results and discussion from 1) baseline test runs, 2) canopy hood test runs, 3) slot hood test runs, and 4) lay-on hood test runs. Section 5 presents a summary of the experimental results along with conclusions and recommendations for

further study. Appendices to the report present raw experimental data, calibration methods, detailed diagrams of the LEV systems, and quality assurance and sampling and analytical procedures.

SECTION 2

DRUM FILLING SIMULATION: ALTERNATIVE APPROACHES

Emissions from drum-filling result primarily from displacement of the vapor-air mixture in the drum during the filling period. These vapors are emitted from the bung hole(s) in the top of the drum. The volumetric flow rate of the emissions from the bung hole(s) equals the vapor-air displacement rate (i.e., the drum-filling rate). The vapor concentration varies with fill method (top or bottom fill; i.e., splash or submerged fill), fill rate, contact time, and the viscosity, vapor pressure, and partial pressure of the liquid. The drum-filling operator's exposure depends on several factors, including emission rate from the drum, evaporation from spilled liquid, room air flow (and the worker's position relative to that air flow), work practices, frequency of drum filling, seasonal variations, random air movements, local exhaust ventilation, and the personal protective equipment worn by the operator.

Several different approaches were evaluated to determine the effectiveness of LEV systems during drum-filling operations. The following three methods of generating vapors were considered to determine the best overall approach based on project objectives, personnel safety, site availability, and budget:

1. Actual repetitive filling of drums with selected liquids.
2. Bubbling air through a volatile liquid in a drum at various rates.
3. Injecting a test gas (such as a fluorocarbon dispersed in air) directly into a drum at various rates.

2.1 REPETITIVE FILLING OF DRUMS WITH SELECTED LIQUIDS

Pumping liquids from a storage tank into 55-gallon drums under carefully controlled conditions would most closely simulate the drum-filling operations employed at industrial sites. This approach would entail pumping liquids

with desired vapor pressures into a 55-gallon drum and measuring the relative effectiveness of the exhaust system by monitoring the concentration of the vapor at the workers' breathing zone in close proximity to the operation. Vapor pressures in the range of 0.01 to 20 mm Hg were desired to generate emissions. The liquids (and their associated properties) considered for this experiment are shown below.

Compound	Vapor pressure, mm Hg at 25°C	Lower explosive limit, volume %	Threshold limit value, ppm
N-octane	10	0.95	300
Ethylene glycol	0.1	3.2	50
Iso butyl alcohol	~10	1.2	50
Perchloroethylene	18.5	Nonflammable	50
20% HCl in water	0.32	Nonflammable	5 (ceiling)

Common solvents such as methylene chloride and trichloroethylene are nonflammable but have vapor pressures well over 20 mm at 25°C. Several other common solvents (e.g., acetone) have high vapor pressures and are also highly flammable. Flammability was an important concern for the experiment because concentrations at the bung hole opening in the drum would be in the volume percent range typical of high emission conditions, thus posing an explosion risk. Common mineral acids such as hydrochloric, nitric, and sulfuric could also be used. The vapor pressure of these acids depends on their concentration and could be varied; they have low TLV's, however, and are very corrosive.

This approach was eliminated from further consideration because of the adverse effects on 1) the safety and potential employee exposure risk associated with the use of actual liquids, 2) the associated spill and disposal concerns, and 3) building-use restrictions prohibiting large quantities of flammable or toxic chemicals at most locations.

2.2 BUBBLING AIR THROUGH LIQUID IN A DRUM

In this approach, air would be sparged into the bottom of a partially filled drum of volatile liquid. This air, which would contain vapor and

droplets after it has bubbled through the liquid, would be emitted from the bung hole. Air rates could be varied to simulate different emissions and filling rates.

This approach appeared attractive because it closely simulated actual filling conditions in that both vapor and droplets would be generated. Also, controlling the air rates could be easily accomplished. Only 30 to 40 gallons of liquid would be required at one time, thus minimizing spill hazards. Hazards due to flammability and toxic fumes would still exist, however, and building use restrictions prohibited even this much quantity of flammable liquid in most cases.

2.3 USE OF TEST GAS

In order to simulate emissions, a relatively inert test gas, such as a fluorocarbon, could be mixed with air and injected into the bottom of a drum at a rate comparable to measured emission rates.¹ The air injection rate would equal the drum-filling rate, and the test gas rate could be adjusted to selected emission rates. This approach avoids any problems with fire, spills, or potential health hazards. No storage drums or pumps would be required, and the accurately known flow rate of the inert gas would provide a means of validating all measurements. Because of its safety and the relative ease with which it would simulate emissions, this approach was selected. Its main drawback was that emissions would consist only of gas mixed with room air; no liquid droplets or mist would be emitted. This was not considered a serious drawback, however, because during drum filling any fine mist emitted could evaporate rapidly to the gaseous phase, and any larger droplets emitted would eventually fall on top of the drum and also evaporate. These factors were accounted for in the study that measured emission rates.¹ The effectiveness of an LEV system could thus be determined by using a gas/air mixture.

SECTION 3

EXPERIMENTAL PROCEDURE

3.1 DRUM FILLING SIMULATION APPROACH

The "test gas" approach discussed in Section 2.3 was selected for simulating drum filling with liquids. This provided a safe method for testing the effectiveness of LEV systems. The two other alternative approaches considered (pumping actual volatile liquids into drums and bubbling air through volatile liquids in a drum) presented potential explosion and health-effects problems. Difluorochloroethane* was selected as the test gas because of its nontoxic nature (TLV = 1000 ppm) and because its concentration in air could be monitored with a flame ionization detector (FID).

3.2 TEST SITE

Experimental testing was conducted at the NIOSH ventilation research facility at 5555 Ridge Avenue, Cincinnati, Ohio. This facility contained an exhaust system that provided the necessary flow for this work. Experimentation was performed in an enclosure 8 ft wide x 8 ft high x 16 ft long. The enclosure was open at one end and an exhaust opening at the opposite end maintained a slow, horizontal airflow (approximately 32 linear feet per minute). This enclosure prevented stray drafts from affecting the hood, and it exhausted any test gas that was not captured by the LEV system. Figure 3-1 shows a diagram of this enclosure and the associated ductwork. Figure 3-2 shows a detailed diagram of the enclosure with experimental equipment in place. Figures 3-3 and 3-4 are photographs of the enclosure and the FID. Details of the custom-built LEV systems are shown in Appendix F.

* Pennwalt Corporation's trade name is "Isotron 142B". Structural formula is $\text{CH}_3\text{-CClF}_2$.

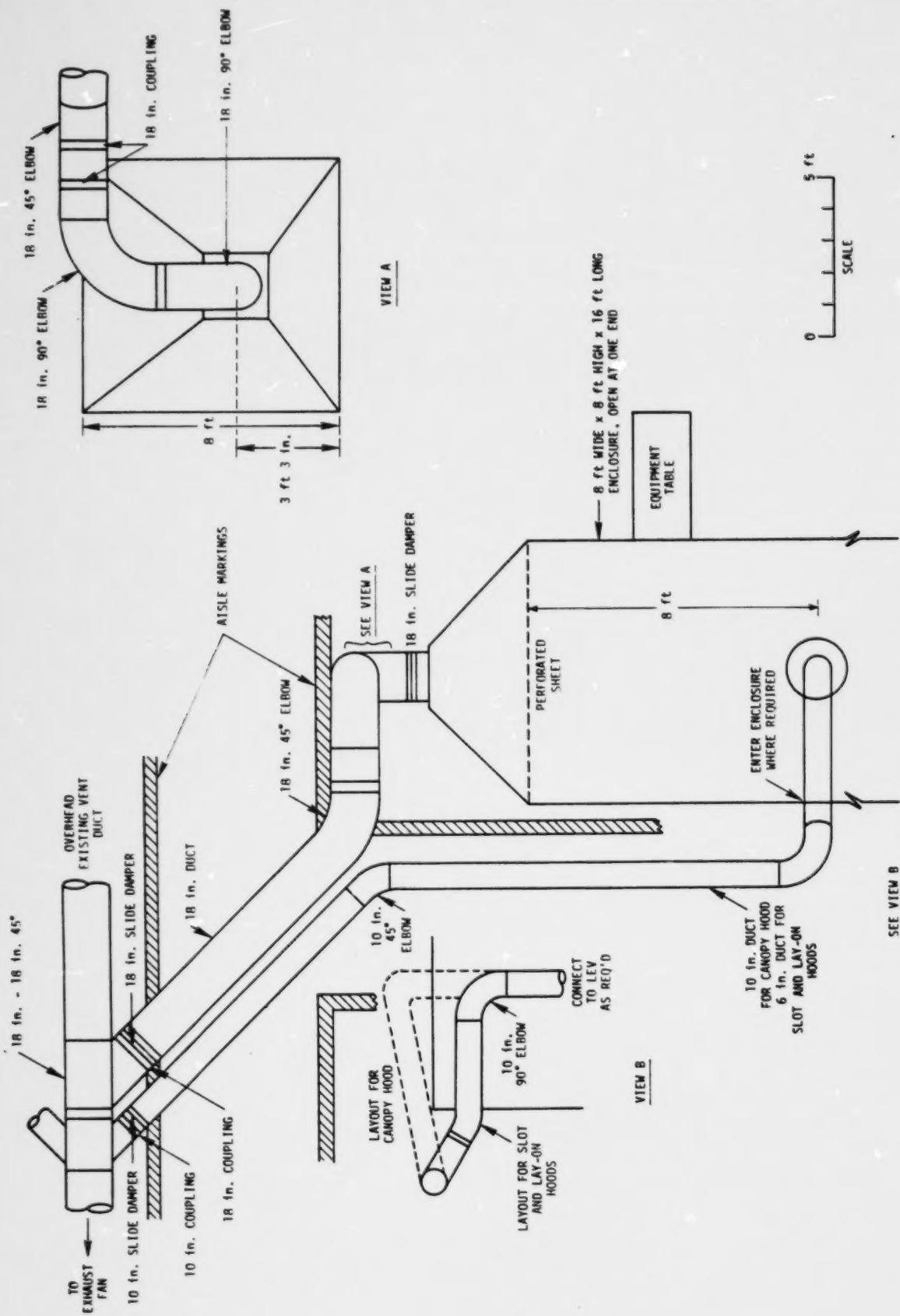


Figure 3-1. Enclosure and associated ductwork.

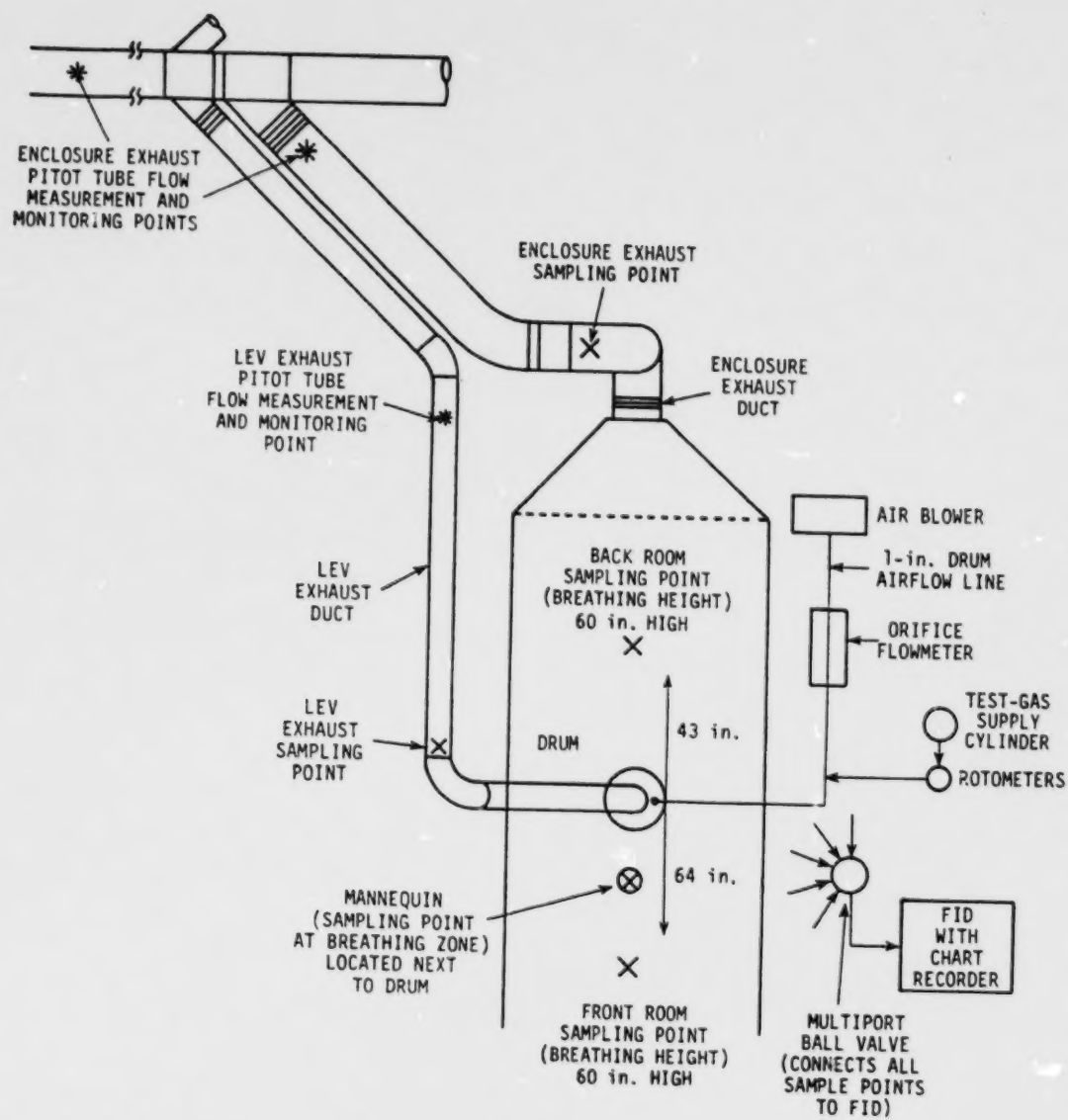


Figure 3-2. Enclosure and experimental equipment.

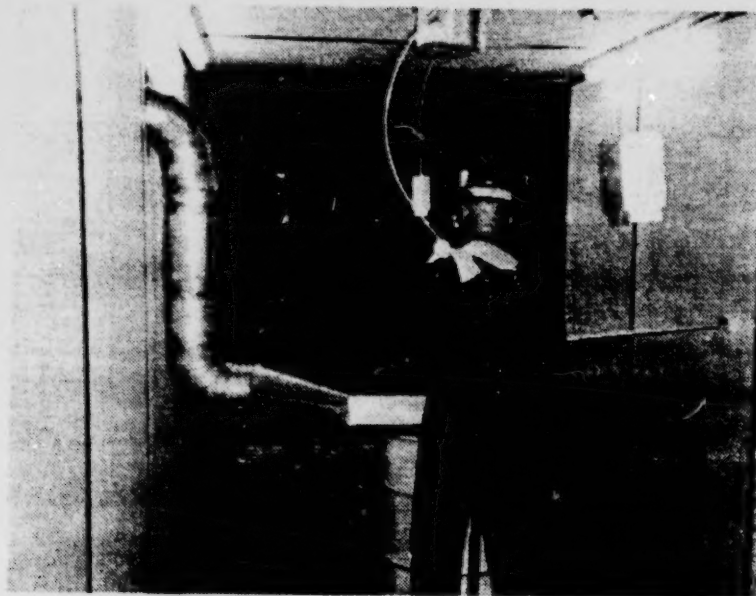


Figure 3-3. Enclosure with mannequin and slot hood in place.
Feed line is coming from the right towards the drum.

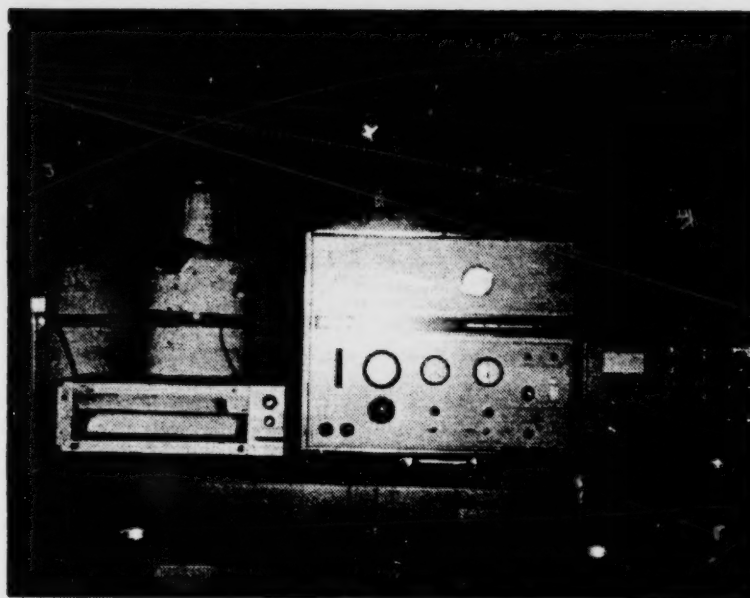


Figure 3-4. Flame ionization detector.

The experimental equipment used in this study was divided into three component systems:

- ° Drum-filling simulation system
- ° LEV and enclosure exhaust system
- ° Test-gas concentration measurement system

3.2.1 Drum-Filling Simulation System

The drum-filling simulation system consisted of an air blower that pushed room air through a 1-inch pipe leading into the enclosure and the drum. The pipe extended down through the 2-inch bung opening in the top of the drum to within 6 inches of the bottom of the drum. Airflow was adjusted by a slide damper on the blower discharge and measured by a calibrated orifice meter.* An inclined manometer was used to measure the orifice pressure drop.

Test gas from storage cylinders was bled into the air line at a tee connection. The rate of test gas feed was regulated and measured by calibrated rotameters.** The test gas mixed with the air flowing to the drum. The gas/air mixture dispersed throughout the drum and then exited through the bung hole.

3.2.2 LEV and Enclosure Exhaust System

LEV and enclosure exhaust flows were provided by the main ventilation system at the NIOSH test facility. Exhaust flows were adjusted with slide-type dampers and measured and monitored with standard pitot tubes. The exhaust flow was measured by traversing the duct with the pitot tube along two orthogonal diameters according to procedures in EPA Methods 1 and 2 (40 CFR Part 60, Subpart A)². During a duct traverse, the velocity head was measured on inclined manometers, and the static head was measured with a U-tube manometer. Airflow temperature was read with a mercury-in-glass thermometer, and the moisture in the room air was measured with a sling psychrometer. These parameters were used to calculate exhaust rates with

* Wet and dry gas meters were used to calibrate the orifice. See Appendix A for details.

** A bubble rate meter was used to calibrate rotameters using test gas from the storage cylinders. See Appendix B for details.

standard equations for pitot tube measurements (as described in the EPA reference methods). In two instances of very low flow rate (below the range measurable with a pitot tube) a hot wire anemometer was used to read velocity at the traverse points. The velocity data was then transformed into a volumetric flow rate. Appendix C presents the results of all exhaust flow measurements.

During the experiment, exhaust flows were monitored by using pitot tubes along with the results of the flow measurement tests. In general, once a flow measurement traverse had been made in a duct, the appropriate slide damper's position was marked. The pitot tube was then fixed at a point of average velocity in the traverse. The velocity head reading at this point from the traverse was then held by making small adjustments with the slide damper. This ensured constant flowrates in the duct.

Because of cyclonic flow patterns in the enclosure exhaust duct, a reliable flow measurement could not be achieved. In lieu of this, a flow traverse measurement was made in the NIOSH laboratory main duct with all exhaust branches closed except the enclosure exhaust. This provided a uniform flow profile measurement of the enclosure exhaust flowrate. This measurement is probably slightly high, however, because of small connection leaks in the laboratory ventilation system. The velocity head pressure in the center of the enclosure exhaust duct was also measured at this time and was used as an indicator of the desired flow during the test series. For the entire experiment, the enclosure exhaust was set at a constant rate of 2040 cubic feet per minute, which yields an average cross-sectional flow of about 32 feet per minute.

Two interchangeable duct sizes were needed for the LEV exhaust. A 6-inch duct was used with the slot and lay-on hoods, whereas a 10-inch duct was used with the canopy hood. The two different sizes were needed because of the different design flowrates used for each hood. Duct size and volumetric flowrate had to be sufficiently compatible for velocity pressure measurements with the pitot tube to be readable on the manometer.

3.2.3 Test Gas Concentration Measurement System

A Beckman 402 FID was used to measure the concentration of test gas at five locations:

- ° Mannequin breathing zone
- ° Front room (breathing height)
- ° Back room (breathing height)
- ° LEV exhaust
- ° Enclosure exhaust

These sampling locations were connected to the FID inlet through Teflon lines and a multiport ball valve. This setup allowed independent monitoring of each sampling point.

The procedures followed were those described in EPA Method 25A.² The detector was calibrated two to three times per day by using certified mixtures of test gas and air at concentrations of 0, 10, 100, and 1000 ppm. For calculation purposes, a lower limit of detection of 0.1 ppm was used. For reporting purposes, the lower limit of detection was 1 ppm. The concentration data were recorded on a strip chart that was marked with the test conditions. The test conditions and measured concentrations were recorded on data sheets.

3.3 TEST PROCEDURES

3.3.1 General Procedures

Experimental data for this study were collected from a number of individual test runs. Each test run was conducted by feeding a selected mixture of test gas and air to the drum. With the particular LEV exhaust hood in place and operating at the desired flow, test gas would emanate from the drum bung hole. All of the test gas fed to the drum would either be collected in the LEV exhaust or escape to the enclosure exhaust. After an equilibrium of test gas feeding and capture had been established at a particular test condition, concentration levels were measured at each of the five sampling points. The test gas feed rate was then adjusted to the next condition and the procedure repeated.

3.3.2 Test Variables

The experimental design consisted of varying four parameters for each individual test run:

- ° Type of LEV
- ° LEV exhaust flow rate
- ° Drum-filling rate
- ° Test gas feed rate

Type of LEV--

The four possibilities for this variable include the three hoods under evaluation (canopy, slot, and lay-on) plus test runs with no LEV present, i.e., baseline runs ("no-LEV runs"). The baseline runs were made to develop information from which to measure the efficiency of the three LEV systems.

LEV Exhaust Flow Rate--

For each of the three types of hoods, runs were performed at two exhaust flowrates ("design" and "low"). The design flowrate for each hood was calculated according to the guidelines in the American Conference of Governmental Hygienists (ACGIH) Ventilation Manual.³ The "low" flow rate settings were determined after operating the LEV system at design flow rates and observing their high efficiencies. No calculated procedure was established for setting the "low" flow rates except for the slot-type hood, for which one-half of the design flow was selected. Table 3-1 gives the measured flow rates used for "design" and "low" designations.

TABLE 3-1. EXHAUST FLOW SETTINGS FOR EACH LEV HOOD SYSTEM^a

Type of hood	Flow designation	Flow rate acfm
Canopy	Design	2560
	Low	440
Slot	Design	323
	Low	162
Lay-On	Design	323
	Low	43

^a Average air flow through enclosure was 32 feet per minute in all tests. (2040 cfm ÷ 64 square feet)

Drum Fill Rate and Test Gas Feed Rate--

In the simulation of emissions from drum-filling, drum fill rate was the volumetric flow rate (in cfm) of air pumped into the drum. This represented the volumetric rate at which a drum is filled with liquid, which is equal to the volumetric rate at which air is displaced from the drum through the bung hole.

Test gas feed rate was the mass flow rate (in milligrams per second) of test gas bled into the air line leading to the drum. This represented the mass flow rate of emissions leaving the drum through the bung hole.

In a previous study, emissions from a drum-filling operation were measured.¹ The report indicates that concentrations of vapor and mist were measured directly at the bung hole under a variety of filling modes and with two separate organic compounds to determine emission rates. The left-hand column of Table 3-2 presents emission rates measured in that study which correspond to the test gas feed rates used in this study. The middle column presents the drum fill rate at which the test gas emissions were measured in the previous study, and were used as the drum fill rates in this study. The right hand column of Table 3-2 is the calculated concentration in parts per million of test gas at the bung hole using the given test gas feed and drum fill rates.

3.4 CALCULATIONS

3.4.1 Test-Gas Flowrate Calculations

It was necessary to calculate the test gas flowrate in standard cubic centimeters per minute at three points in the test site: 1) the feed into the drum, 2) the LEV exhaust duct, and 3) the enclosure exhaust duct. The results of these calculations were used in efficiency and mass balance calculations. Figure 3-5 illustrates the flow of test gas in and out of the enclosure.

Feed Into Drum--

The test gas flowrate feed into the drum was regulated and measured with calibrated rotameters. The rotameter calibration produced a direct plot of

TABLE 3-2. RATES OF AIR AND TEST GAS INJECTED INTO 55-GALLON DRUM

Test gas feed rate, mg/s ^a	Drum fill rate, cfm ^a	Calculated concentration, ppm ^b
340	3.34 (25 gal/min)	51,810
180	1.47 (11 gal/min)	62,320
160	3.34	24,380
50	1.47	17,310
80	3.34	12,190
25	1.47	8,655
17	3.34	2,590
4	1.47	1,385
4	3.34	609
1	1.47	346

^a Based on emissions measured by Midwest Research Institute and presented in their report entitled "Occupational Exposure Assessment," EPA Contract 68-02-3939, Assignment 10, November 26, 1985. p. 70.

^b Parts per million $\text{CH}_3\text{-CClF}_2$ by volume at bung hole at equilibrium.

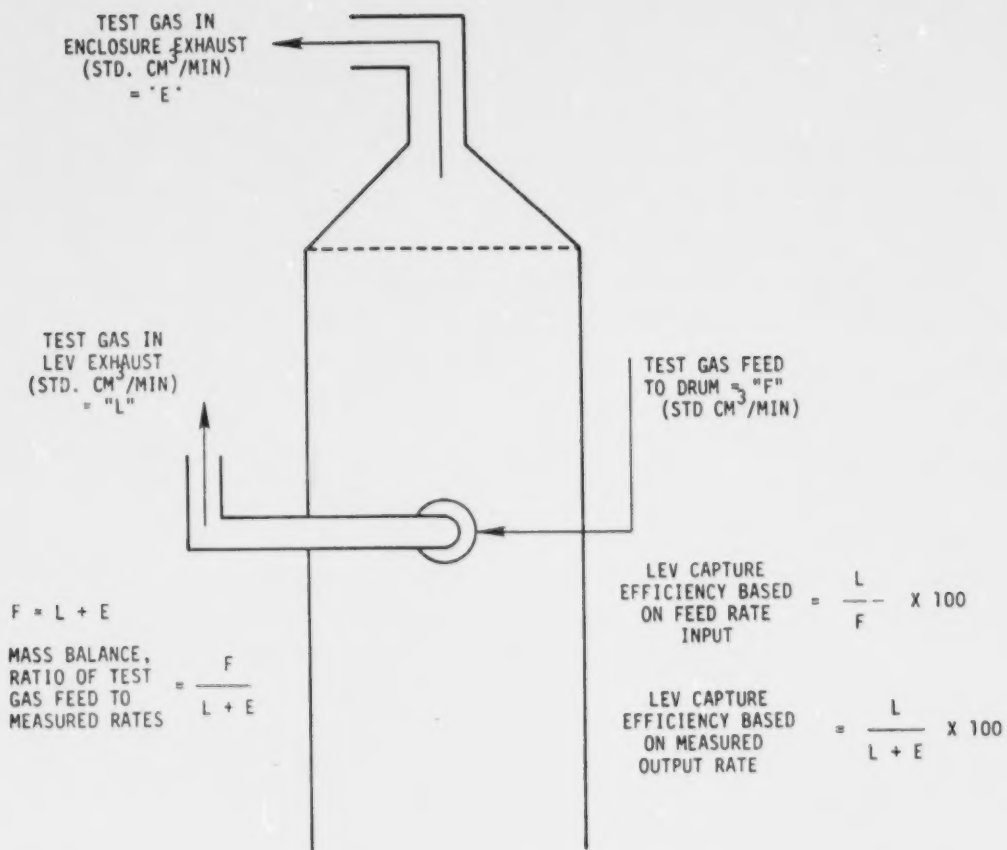


Figure 3-5. Test gas flow into and out of enclosure.

test gas flowrate from the cylinders (actual cubic centimeters/minute) versus rotameter setting. The plot was then adjusted to standard cubic centimeters/minute versus rotameter setting. Emission rates for the test gas (difluoro-chloroethane) from Table 3-2 (in milligrams/second) were converted to standard cubic centimeters/minute by assuming the gas to be ideal. The rotameter settings corresponding to these flowrates were then used for the experiment.

LEV and Enclosure Exhaust Ducts--

Test gas flowrates in the LEV and enclosure exhaust ducts for a particular run were calculated by multiplying the exhaust airflows (in standard cubic feet per minute) by the measured exhaust concentrations. Exhaust airflow was converted to standard conditions with daily readings of room temperature and barometric pressure, both of which remained steady from day to day throughout the entire experiment. For example:

$$\text{Exhaust flow (scfm)} = \text{exhaust flow (acfm)} \times \frac{\text{barometric press (in. Hg)}}{29.92} \times \frac{530}{\text{Temp (}^{\circ}\text{F)} + 460}$$

$$\begin{aligned} \text{Test gas flowrate in exhaust (std. cm}^3\text{/min)} &= [\text{exhaust flow (scfm)}] \times [\text{exhaust conc. (ppm)}] \\ &\div (1 \times 10^6) \times [2.83 \times 10^3 \frac{\text{cm}^3}{\text{ft}^3}] \end{aligned}$$

3.4.2 LEV Efficiency Calculations

Three methods were used to calculate LEV efficiency in this report.

LEV Efficiency Based on Mannequin Breathing Zone Concentration--

This LEV efficiency is based on the change in test gas concentration at the mannequin's breathing zone when LEV is in place compared with levels when no LEV is present. Two series of test runs were performed for each drum fill rate/test gas feed rate with no LEV in place. The average of these runs served as baseline ("no-LEV") information for calculating efficiency. The LEV efficiency based on the concentration at the mannequin's breathing zone was calculated for each test configuration by the following equation:

$$\begin{aligned} \text{LEV efficiency based on mannequin's breathing zone concentration} &= \frac{\text{Average breathing zone conc. with no LEV} - \text{Breathing zone conc. with LEV}}{\text{Average breathing zone conc. with no LEV}} \times 100 \end{aligned}$$

LEV Capture Efficiency Based on Test Gas Feed Rate Input

Another measure of LEV efficiency is the percentage of test gas fed to the drum that is captured by the LEV.

$$\text{LEV capture efficiency based on feed input rate} = \frac{\text{Test gas flow rate in LEV exhaust (std. cm}^3\text{/min)}}{\text{Test gas feed rate to drum (std. cm}^3\text{/min)}} \times 100$$

LEV Capture Efficiency Based on Measured Test Gas Output Rate--

A third method of measuring hood efficiency is the percentage of test gas leaving the enclosure that is exhausted through the LEV system.

$$\text{LEV capture efficiency based on measured output rate} = \frac{\text{Test gas flowrate in LEV exhaust (std. cm}^3\text{/min)}}{\text{Test gas flowrate in LEV exhaust (std. cm}^3\text{/min)} + \text{Test gas flowrate in enclosure exhaust (std. cm}^3\text{/min)}}$$

LEV efficiency based on mannequin breathing zone concentration should be the best measure of LEV effectiveness because it directly measures the reduction in mannequin exposure caused by the LEV. These concentrations may have been lower than otherwise expected, however, because the mannequin was located upstream of the emission source. LEV capture efficiency based on test gas feed rate is considered (in this experiment) the next best measure of LEV effectiveness because it involves fewer measured values in its calculation and does not include the air flow measurement for the enclosure. LEV capture efficiency based on measured test gas output rate is considered the least accurate measure of capture efficiency.

3.4.3 Mass Balance, Ratio of Test Gas Feed to Measured Rates

As shown in Figure 3-5, the amount of test gas fed to the drum should theoretically equal the amount of test gas leaving through the LEV and enclosure exhausts. The ratio of the test gas feed to the test gas exhausted is a composite measure of the accuracy of the test. The closer this ratio is to 1.00, the more accurate the test.

$$\text{Ratio of test gas feed to measured rates} = \frac{\text{Test gas feed rate to drum (std. cm}^3\text{/min)}}{\text{Test gas flowrate in LEV exhaust (std. cm}^3\text{/min)} + \text{Test gas flowrate in enclosure exhaust (std. cm}^3\text{/min)}}$$

SECTION 4

RESULTS AND DISCUSSION

The results of the experimentation are presented in the following four subsections. The data were gathered in series of test runs denoting the type of hood and the exhaust air flow rate as follows:

- ° Baseline (Series "B" and "F")
- ° Canopy hood at design flow (Series "A")
- ° Canopy hood at low flow (done in conjunction with the Series "A") runs)
- ° Slot hood at design flow (Series "C")
- ° Slot hood at low flow (Series "G")
- ° Lay-on hood at design flow (Series "D")
- ° Lay-on hood at low flow (Series "E")

It should be noted that a canopy hood would normally not be used in industry for drum filling. This design would be awkward to use in this application and it could force the worker to stand directly in the path of the contaminant.

4.1 BASELINE CONDITIONS

Table 4-1 contains a summary of test gas concentrations measured at the mannequin breathing zone under 10 simulated drum-filling emission conditions with no LEV in place. Duplicate series of test runs ("B" and "F") were made under these conditions. The average concentration from the two series was computed and subsequently used as a baseline concentration in the calculation of LEV efficiency based on mannequin breathing zone concentration for the canopy, slot, and lay-on hood LEV configurations.

Table 4-1. Baseline Mannequin Breathing Zone Concentrations

Drum fill rate, cfm	Test gas feed rate, mg/sec	Mannequin breathing zone concentration, ppm		
		Series B	Series F	Average
1.47	1	8	11	10
1.47	4	45	51	48
1.47	25	109	167	138
1.47	50	95	134	115
1.47	180	32 & 70†	65	56
3.34	4	11	5	8
3.34	17	97	29	63
3.34	80	259	389	324
3.34	160	207	119	163
3.34	340	149	76	113

† Duplicate test run

The mannequin breathing zone concentrations varied widely between the two series indicating that even slight changes in the room's air currents affected these values (some variations in concentration are always present with short-term samples of this type). Also noticed during these runs was the change in mannequin concentration with the change in test gas feed rate. The mannequin concentration initially increased with increasing test gas feed rates. However, at higher feed rates, the mannequin concentration decreased. One explanation for this phenomenon is that as the test gas feed rate increased while the drum-fill rate stayed the same, the density of the gas mixture leaving the drum increased. The mannequin sampling point was 3 feet above the bung hole, and an increase in gas density would reduce the exposure to the mannequin by decreasing the vertical dispersion of the gas. To test this theory, a sample probe was placed on top of the drum opposite the bung hole during a series of runs. Concentration levels measured at this point and at the mannequin breathing zone are displayed in Figures 4-1 and 4-2. The test gas concentration measured at the top of the drum increased with each increase in the test gas feed rate. Although this test does not rigorously prove the theory, it does lend credence to it. The cooling of the test gas stream because of expansion from the high pressure of the storage cylinder would also cause a significant increase in the density of the gas mixture.

Test-gas concentrations in the enclosure exhaust duct (shown in Table 4-2) correlated well between the two series and with the test gas feed rate (except at the very low feed and fill rates). As discussed in Section 3.2.2, the enclosure exhaust rate had to be measured in the main laboratory exhaust duct with all branches closed except the one leading to the enclosure exhaust. Because numerous small connection leaks are likely to be present in the laboratory exhaust system, this flow reading was probably higher than what was actually flowing through the enclosure exhaust duct. This flow measurement factored directly into each calculation of test gas flowrate, yielding higher test gas flowrate results than were actually present in the enclosure exhaust. As such, mass balance calculations show that more test gas was apparently transported through the enclosure exhaust than was fed to the drum. In each test run (except in series "B" at low feed and fill

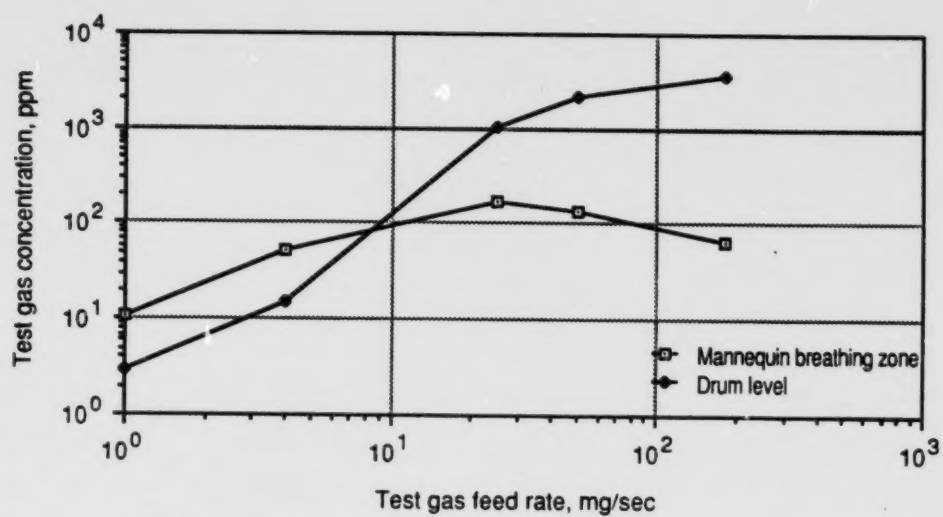


Figure 4-1. Comparison of mannequin and drum level concentrations for Test Series F at 1.47 cfm drum fill rate.

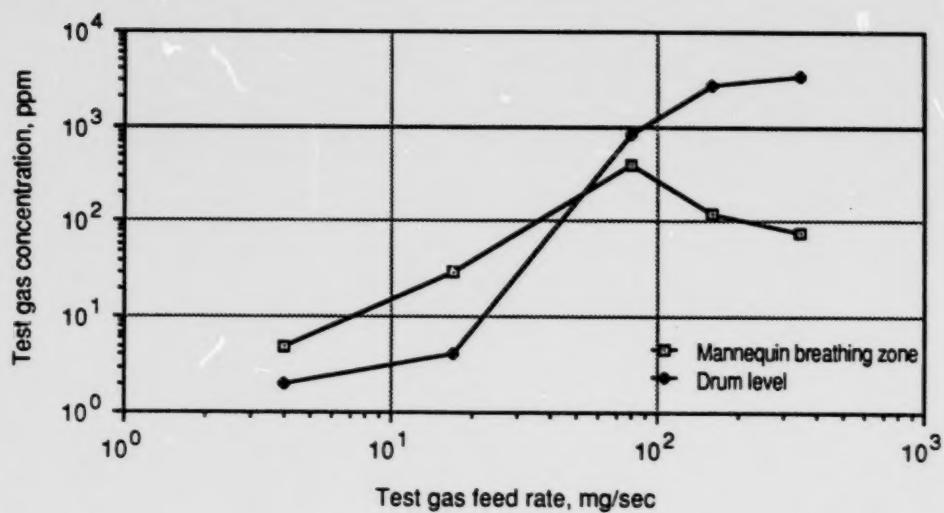


Figure 4-2. Comparison of mannequin and drum level concentrations for Test Series F at 3.34 cfm drum fill rate.

Table 4-2. Baseline Enclosure Exhaust Concentrations

Drum fill rate, cfm	Test gas feed rate, mg/sec	Enclosure exhaust concentration, ppm			Mass balance, ratio of test gas feed to measured output rates	
		Series B	Series F	Average	Series B	Series F
1.47	1	0	1	<1	-	0.23
1.47	4	1	1	1	0.94	0.92
1.47	25	8	8	8	0.74	0.73
1.47	50	14	15	15	0.85	0.77
1.47	180	54 & 55*	51	53	0.79 & 0.77†	0.82
3.34	4	1	1	1	0.93	0.93
3.34	17	5	5	5	0.80	0.80
3.34	80	25	23	24	0.75	0.82
3.34	160	45	42	44	0.84	0.89
3.34	340	102	111	107	0.78	0.72

† Duplicate test run

rates), the "mass balance ratio of the test gas feed to measured rates" was well below 1.00.

Test gas concentrations measured at the "backroom" sampling point are presented in Table 4-3. These concentrations, though fairly consistent between the two series, did not correlate well with the test gas feed rate. This also lends credence to the theory that density changes affected dispersion of the test gas in the enclosure. Comparing backroom concentrations to enclosure exhaust concentrations for individual test runs shows that the test gas was not uniformly dispersed across the cross section of the enclosure. If the test gas was distributed uniformly across the enclosure, the backroom and enclosure exhaust concentrations would be nearly identical for any given test run.

Front room concentrations were monitored in test series "B" and in subsequent runs with LEV hoods in place. However, because no significant levels were measured, monitoring of this sample point was discontinued for the entire experiment.

4.2 CANOPY HOOD

Photographs of the canopy hood used in this study appear in Figures 4-3 and 4-4. Table 4-4 presents data obtained using the canopy hood at a design flow of 2560 acfm under eight simulated drum-filling emission conditions. The data show that the canopy hood was highly effective in that no significant levels of test gas were noted at the mannequin, enclosure exhaust, and backroom sampling points. As such, the hood efficiency based upon mannequin concentration was nearly 100 percent for all runs. As mentioned earlier, however, this type of hood would not be used in practice for drum filling.

The LEV capture efficiencies based on test gas feed and measured output rates were generally very high. Excluding the test run at a drum-fill rate of 1.47 cfm and test gas feed rate of 4 mg/sec (capture efficiency data for this run are considered invalid based on the poor mass balance ratio of 0.57), the LEV capture efficiencies based on test gas feed rate ranged between 93 and 100 percent. The LEV capture efficiencies based on measured test gas output rate averaged 100 percent. Because the calculation for LEV efficiency based on measured test gas output rate includes the calculation

Table 4-3. Baseline Back Room Concentrations

Drum fill rate, cfm	Test gas feed rate, mg/sec	Back room concentration, ppm		
		Series B	Series F	Average
1.47	1	1	1	1
1.47	4	2	<1	1
1.47	25	1	<1	<1
1.47	50	1	1	1
1.47	180	1 & 1†	1	1
3.34	4	11	11	11
3.34	17	42	43	43
3.34	80	10	9	10
3.34	160	8	7	8
3.34	340	3	3	3

† Duplicate test run



Figure 4-3. Canopy hood (pictured outside of enclosure).

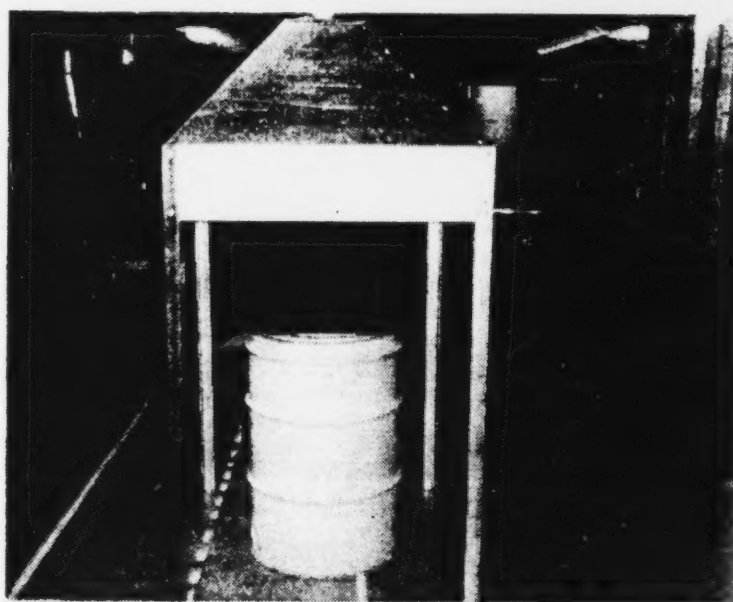


Figure 4-4. Canopy hood (pictured outside of enclosure).

Table 4-4. Performance of Canopy Hood at Design Air Flow (2560 cfm) - Test Series A

Drum fill rate, cfm	Test gas feed rate, mg/sec	Concentration, ppm				LEV capture efficiency, percent			Mass balance, ratio of test gas feed to measured output rates
		Mannequin breathing zone	Enclosure exhaust	LEV exhaust	Back room	Based on test gas feed rate	Based on test gas output rate	Based on mannequin concentration	
1.47	4	0	0	1	1	130	100	100	0.75
1.47	25	0	0	5	0	110	100	100	0.94
1.47	50	1	0	9	0	95	100	99	1.05
1.47	80†	0	0	14	1	93	100	-	1.08
1.47	340†	0	0	67	0	100	100	-	0.96
3.34	17	0	0	3	0	94	100	100	1.07
3.34	80	0	0	15	0	99	100	100	1.01
3.34	340	0	0	64	0	100	100	100	1.00

† Not part of test plan.

for test gas flowrate through the enclosure exhaust (which is assumed to be slightly inaccurate, see Sections 3.2.2 and 4.1), LEV efficiency based on test gas feed rate is considered the more accurate of the two.

The data from Table 4-4 show no correlation between test gas feed rate and LEV efficiency. However, a slight correlation is noticed between drum fill rate and LEV efficiency. At the higher fill rate of 3.34 cfm, LEV efficiencies are consistently around 99 to 100 percent, while the slightly lower efficiencies are confined to runs with a low fill rate. At the higher drum-fill rate, the velocity and upward momentum of the test gas stream exiting the drum bung hole is higher. Because the canopy acts as a receiving hood above the drum, the higher velocity of the gas stream exiting the drum "pushes" the test gas into the hood, increasing capture efficiency.

The mass balance ratio of the feed to measured rates ranged between 0.94 and 1.07 (excluding the test at 1.47 cfm and 4 mg/sec). This reflects an excellent correlation between the amount of test gas known to be introduced into the drum to the amount actually measured. The reason for the improved mass balance ratio over those found in the "baseline" runs lies in the extremely low enclosure exhaust gas concentration levels. Referring to the test gas flow rate and mass balance ratio calculations in Sections 3.4.1 and 3.4.3, respectively, the enclosure exhaust gas concentration levels are used along with the enclosure exhaust air flow to calculate test gas flow rate in the enclosure exhaust. This in turn is used in the mass balance ratio calculation. As indicated in Sections 3.2.2 and 4.1, the enclosure exhaust air flow rate is considered to be in error. This error, however, is minimized in the calculation of test gas flow rate in the enclosure and the mass balance ratio as the enclosure exhaust concentration approaches zero.

Although the data indicate that the canopy hood was highly effective, several factors must be taken into consideration before making comparisons with the other hoods. First, due to the size and shape of the canopy hood, the mannequin had to be placed 34 inches behind the drum while it stood only 16 inches behind when using the other hoods or no hood. Second, again due to the size and shape of the canopy hood, the breathing zone of the mannequin was "shielded" by the hood from the test gas coming from the drum, thus blocking the mannequin's line of sight to the drum bung hole. Because the mannequin could not move from this position, test gas levels measured at its

breathing zone during the canopy hood runs could not be representative of "real" conditions. LEV capture efficiencies for the canopy hood are comparable to the other hoods because mannequin breathing zone concentration does not figure into their calculations.

This conclusion is supported by data from runs performed with the canopy hood in place but with reduced air flow (see Table 4-5). In this situation the mannequin concentration was never greater than 3 ppm and usually not detectable. The test runs with the exhaust air flow rate at 33 cfm were made with the damper on the LEV exhaust duct shut. Even though theoretically closed, a flow of 33 cfm was measured in the LEV exhaust. Two additional runs were performed with the damper slightly open (measured flow rate of 440 cfm). The resulting mannequin breathing zone and enclosure exhaust concentrations were below 1 ppm.

4.3 SLOT HOOD

The slot hood was operated at two exhaust flow rates, 323 cfm and 152 cfm, under 10 simulated drum-filling emission conditions. Photographs of the slot hood appear in Figures 4-5 and 4-6.

4.3.1 Slot Hood at 323 cfm

The flow setting of 323 cfm represents ACGIH ventilation guide recommendations for slot hoods used for 2-foot diameter drums. At this flow rate, the slot hood was highly effective in that the test gas concentrations at the mannequin breathing zone, enclosure exhaust, and backroom sampling points were 1 ppm or less for all runs (see Table 4-6).

LEV efficiency based on mannequin breathing zone concentration was 99 or 100 percent for each test run at this exhaust flowrate. LEV capture efficiency, based on test gas feed rate, ranged between 84 and 140 percent, while LEV capture efficiency based on measured test gas output rate ranged between 95 and 100 percent.

It should be noted that the extreme values for the LEV capture efficiency based on test gas feed rate (84 and 140 percent) occurred during test runs with the low test gas feed rates (1 and 4 mg/sec). Test gas concentration levels during these runs were low and any error in measurement was amplified in the efficiency calculation. This error is reflected in the poor

Table 4-5. Performance of Canopy Hood at Reduced Exhaust Flow - Test Series A

Drum fill rate, cfm	Test gas feed rate, mg/sec	LEV exhaust rate, acfm	Concentration, ppm		
			Mannequin	Enclosure exhaust	Back room
1.47	1	33	0	0	—
1.47	4	33	0	2	2
1.47	25	33	0	9	7
1.47	50	33	0	14	2
1.47	80	33	0	21	—
1.47	340	33	0	104	3
3.34	17	33	0	1	12
3.34	80	33	3	—	—
3.34	340	33	3	—	—
3.34	80	440	0	0	—
3.34	340	440	0	0	—



Figure 4-5. Slot hood with feed line positioned through drum bung hole.

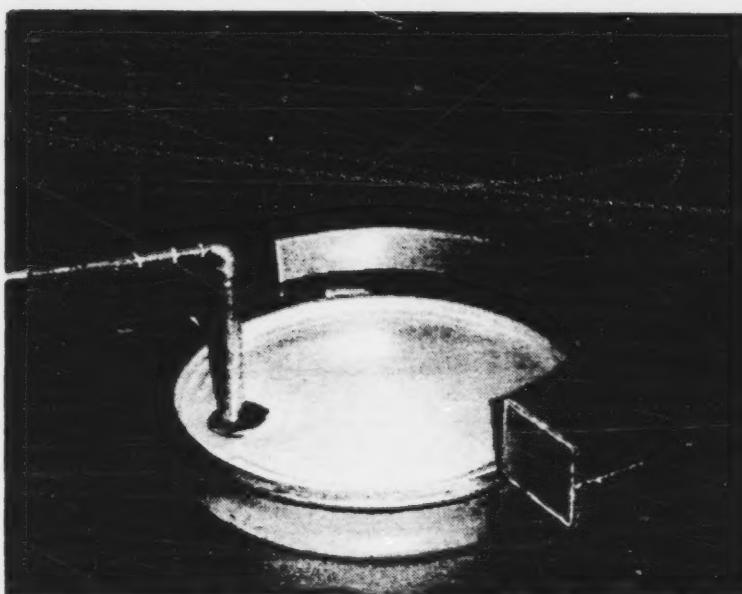


Figure 4-6. Slot hood.

Table 4-6. Performance of Slot Hood at Design Air Flow (323 cfm) - Test Series C

Drum fill rate, cfm	Test gas feed rate, mg/sec	Concentration, ppm				LEV capture efficiency, percent			Mass balance, ratio of test gas feed to gas measured to output rates
		Mannequin breathing zone	Enclosure exhaust	LEV exhaust	Back room	Based on test gas feed rate	Based on test gas output rate	Based on mannequin concentration	
1.47	1	0	0	2	0	140	100	100	0.73
1.47	4	1	0	5	1	84	100	98	1.19
1.47	25	0	0	38	1	100	100	100	0.98
1.47	50	0	0	76	0	100	100	100	0.98
1.47	180	0 & 1†	0 & 0†	273 & 282†	0 & 1†	100 & 100†	100 & 100†	98 & 100†	0.96 & 1.00†
3.34	4	0	0	5	0	84	100	100	1.19
3.34	17	0	0	25	0	98	100	100	1.02
3.34	80	0 & 1†	0 & 1†	115 & 125†	0 & 1†	95 & 100†	95 & 100†	100 & 100†	0.91 & 1.05†
3.34	160	1	1	236	1	99	97	99	0.99
3.34	340	0	0	545	0	110	100	100	0.94

† Duplicate test run.

mass balance ratio for the runs with test gas feed rates of 1 and 4 mg/sec. Excluding these three runs, the LEV capture efficiency based on test gas feed rate ranges between 95 and 110 percent, while the LEV capture efficiency based on measured test gas output rate ranged between 95 and 100 percent.

No correlation between test gas feed rate and LEV efficiency was found. Also, there were no significant differences in LEV efficiency between the two drum-fill rates.

Mass balance ratios ranged between 0.73 and 1.19. Excluding the runs with test gas feed rates of 1 and 4 mg/sec, the mass balance ratios ranged between 0.96 and 1.05.

4.3.2 Slot Hood at 152 cfm

After operating the slot hood at its design flowrate and finding it highly effective, the flowrate was decreased to 152 cfm. At this flowrate, measurable test gas concentrations were found at the mannequin, enclosure exhaust, and backroom sampling points (see Table 4-7).

LEV efficiency based on mannequin breathing zone concentration ranged between -120 and 100 percent. The efficiency of -120 percent represents an increase in the mannequin breathing zone concentration when using the slot hood at 152 cfm (18 ppm) over the average concentration measured with baseline conditions (8 ppm). An explanation for this phenomenon is that the slot hood only partially pulled the test gas across the top of the drum allowing air currents around the mannequin and the drum to sweep the test gas towards the breathing zone. The difference could also represent normal random variations.

LEV capture efficiency based on test gas feed rate ranged from 55 to 110 percent. LEV capture efficiency based on measured test gas output rate ranged between 56 and 100 percent.

There was a marked difference in hood efficiency between the two fill rates of 1.47 and 3.34 cfm. At 1.47 cfm, the LEV efficiency based on mannequin breathing zone concentration was always above 90 percent, while at 3.34 cfm LEV efficiency was always below 40 percent. A similar trend is apparent, to a less dramatic degree, with the two LEV capture efficiency calculations. The difference in LEV efficiency between the two fill rates is caused by the increased drum emission velocity at the bung hole inherent with the increased

Table 4-7. Performance of Slot Hood at Low Air Flow (152 cfm) - Test Series G

Drum fill rate, cfm	Test gas feed rate, mg/sec	Concentration, ppm				LEV capture efficiency, percent			Mass balance, ratio of test gas feed to gas measured to output rates
		Mannequin breathing zone	Enclosure exhaust	LEV exhaust	Back room	Based on test gas feed rate	Based on test gas output rate	Based on mannequin concentration	
1.47	1	0	0	3	0	97	100	100	1.04
1.47	4	1	0	13	0	100	100	98	0.97
1.47	25	2	0.1	80	0.1	100	98	99	0.97
1.47	50	7	2	168	0	110	86	94	0.82
1.47	180	5	23	389	0	68	56	91	0.82
3.34	4	18	1	10	1	79	43	-120	0.54
3.34	17	60	2	30	1	55	53	5	0.95
3.34	80	219	6	219	3	87	73	32	0.84
3.34	160	99	5	519	1.1	100	89	39	0.86
3.34	340	72	23	819	0	75	73	36	0.96

fill rate. The higher velocity at the bung hole provides a greater potential for the test gas to escape the pull of the slot hood.

Conflicting relationships between LEV efficiency and test gas feed rate were observed. At the 1.47 cfm fill rate, LEV efficiency based on both the mannequin breathing zone concentration and the test gas output rated decreased with increasing test gas feed rates. At the 3.34 cfm fill rate, these efficiencies increased with increasing test gas feed rates. No correlation was noted using LEV capture efficiency based on test gas feed rate.

Mass balance ratios for these test runs ranged between 0.82 and 1.04. The reason the mass balance ratios are lower for this LEV configuration is that significant levels of test gas were measured at the enclosure sampling point. As explained in Sections 3.2.2 and 4.1, the enclosure exhaust test gas flowrates are estimated to be less than calculated because of a problem in exhaust flow measurement. Because the slot hood at 152 cfm was not very effective, significant amounts of test gas were exhausted through the enclosure, thus introducing this error into the calculations.

4.4 LAY-ON HOOD

Photographs of the lay-on hood appear in Figures 4-7 and 4-8. Three test runs were made with the lay-on hood at the ACGIH design exhaust flow rate of 323 cfm. Four test runs were performed at a lower exhaust flow rate of 43 cfm. In all instances, the hood showed very high effectiveness as can be seen in Table 4-8 and 4-9. In all runs, the mannequin, enclosure exhaust, and backroom sampling point concentrations were 1 ppm or less. Because of this high effectiveness, it would have been redundant to operate the hood at all 10 simulated drum-filling emission conditions. The effectiveness of this hood is enhanced by its tight-fitting design, which essentially prevents any emissions from escaping.

The mass balance ratios of test gas feed to measured output rates ranged between 0.93 and 0.94 for the lay-on hood at design flow, while they ranged between 0.85 and 1.12 at the lower exhaust flow. The poor mass balance ratios encountered with the lower flow during test runs at 80, 160, and 340 mg/sec are probably due to the LEV exhaust concentrations being in excess of the FID calibration gas concentrations (0, 10, 100, and 1000 ppm).

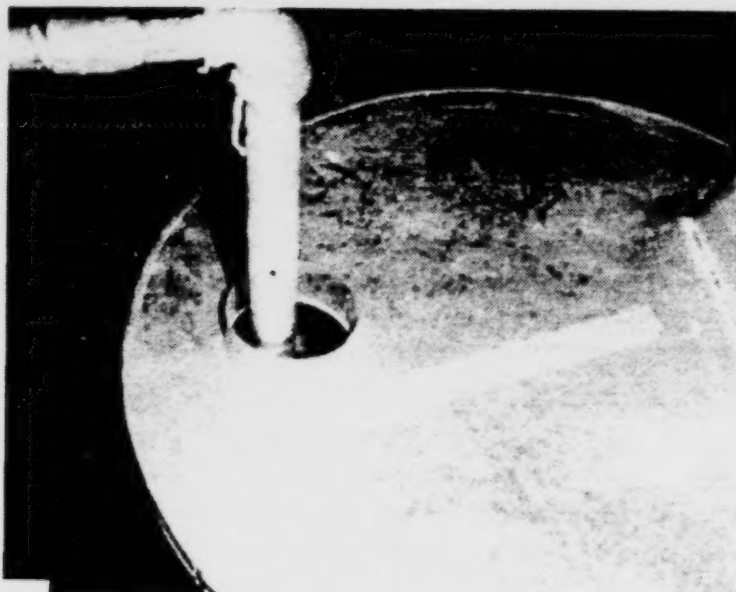


Figure 4-7. Lay-on hood, (pictured outside of enclosure) with feed line positioned through the hood openers and the drum bung hole.



Figure 4-8. Lay-on hood (outside of enclosure) with hood exhaust on the right and hood opening for feed line on the left.

Table 4-8. Performance of Lay-on Hood at Design Air Flow (323 cfm) - Test Series D

Drum fill rate, cfm	Test gas feed rate, mg/sec	Concentration, ppm				LEV capture efficiency, percent		Mass balance, ratio of test gas feed to measured output rates
		Mannequin breathing zone	Enclosure exhaust	LEV exhaust	Back room	Based on test gas feed rate	Based on test gas output rate	
1.47	50	1	0	80	-	110	100	0.94
3.34	160	0	0	256	1	110	100	0.94
3.34	340	0	0	550	1	110	100	0.93

Table 4-9. Performance of Lay-on Hood at Low Air Flow (43 cfm) - Test Series E

Drum fill rate, cfm	Test gas feed rate, mg/sec	Concentration, ppm				LEV capture efficiency, percent			Mass balance, ratio of test gas feed to gas measured to output rates
		Mannequin breathing zone	Enclosure exhaust	LEV exhaust	Back room	Based on test gas feed rate	Based on test gas output rate	Based on mannequin concentration	
1.47	50	0	0	659	0	120	100	100	0.85
3.34	80	0	0	1011	0	110	100	100	0.89
3.34	160	0	0	2085	0	120	100	100	0.86
3.34	340	0	0	3406	0	89	100	100	1.12

SECTION 5

SUMMARY OF RESULTS, CONCLUSIONS, AND RECOMMENDATIONS

5.1 SUMMARY OF RESULTS

In five of the six LEV hood/exhaust flowrate configurations studied, test gas levels were found to be below the detection limit of 1 ppm at the mannequin breathing zone, enclosure exhaust, and backroom sampling points. Only in the test series using the slot hood at the "low" exhaust flowrate (152 cfm) were there significant amounts of test gas found at these points. A summary of LEV efficiency ranges measured during the study appears in Table 5-1. These ranges exclude information from test runs in which accurate data were not obtainable.

LEV efficiencies based on mannequin breathing zone concentrations were 99 and 100 percent for each LEV/hood exhaust flowrate configuration except for the slot hood at "low" exhaust flow (152 cfm). The results of one test run with the slot hood at low exhaust flow indicate that the test gas concentration at the mannequin breathing zone was increased by the LEV over concentrations measured at baseline conditions. Baseline conditions for the evaluation of efficiency based on mannequin breathing zone concentration were established with test runs using no LEV. Duplicate series of runs with no LEV indicated large fluctuations in the mannequin breathing zone concentration. The fluctuations were probably caused by changes in the enclosure air currents.

For the canopy hood, LEV efficiencies based on mannequin breathing zone concentration are likely misleading because the size and shape of the hood physically shielded the mannequin from the drum emissions. An actual drum filling operator would not be shielded as the mannequin was in this study and would be exposed to higher emissions. Furthermore, this type of hood design would not be used in industry for drum filling operations.

Table 5-1. LEV Efficiency Summary†

Hood type	LEV exhaust air flow rate	Drum fill rate, cfm	LEV capture efficiency, percent		
			Based on test gas feed rate	Based on test gas output rate	Based on mannequin concentration
Canopy	Design	1.47	93 to 100	100	Data not reliable
		3.34	94 to 100	100	Data not reliable
	Low	1.47	No data	No data	No data
		3.34	No data	No data	No data
Slot	Design	1.47	100	100	98 to 100
		3.34	95 to 100	95 to 100	99 to 100
	Low	1.47	68 to 110	56 to 100	91 to 100
		3.34	55 to 100	43 to 89	-120 to 39
Lay-on	Design	1.47	110	100	99
		3.34	110	100	100
	Low	1.47	120	100	100
		3.34	Data not reliable	Data not reliable	100

† Information presented was generated only with data known to be accurate.

LEV capture efficiencies also indicate that all of the hoods were highly effective, except for the slot hood at low exhaust flow. The capture efficiency values are more subject to error than the test gas concentration levels and the efficiency based on mannequin breathing zone concentration because they are calculated from a number of measured values. LEV capture efficiency based on test gas feed rate is more accurate than efficiency based on test gas output rate because it does not include the enclosure exhaust air flow measurement which is felt to be in error.

No correlation was established between test gas feed rate (i.e., test gas emission concentration) and LEV efficiency with any of the hoods. Drum-fill rate had a dramatic influence on slot hood efficiency at low exhaust flow and a small effect on canopy hood efficiency at design exhaust flow.

Data from baseline test runs showed that test gas concentration levels at the mannequin breathing zone increased with increasing test gas feed rate up to a point, from which they leveled off and declined. This is probably caused by an increase in the density of the vapor-air mixture leaving the drum as the test gas feed rate increases. This increase in density would cause less vertical dispersion of the test gas.

The mass balance ratio of test gas feed to measured output rate served as a check on the accuracy of test gas measurements. The average mass balance ratio for all test runs averaged 0.93 with a standard deviation of 0.26. Excluding the runs with test gas feed rates of 1 and 4 mg/sec (because of amplified error in test gas flowrate calculations caused by measurement errors with low test gas concentration levels) and the runs in which test gas concentrations exceeded the calibration range of the FID (i.e., those runs with the lay-on hood at low exhaust flowrate and 3.34 cfm drum-fill rate), the mass balance ratio averaged 0.90 with a standard deviation of 0.10. Most of the test gas flow measurement error in this study originated from problems in accurately measuring the enclosure exhaust air flow rate. In the test series with extremely low enclosure exhaust concentrations, this error was minimized as noted by mass balance ratios much closer to the ideal of 1.00.

The precision of test gas concentration measurements was monitored with 12 duplicate test runs. Ten of the duplicate runs were performed with the two series of test runs using no LEV (i.e., Test Series "B" and "F" were

duplicates; therefore, the 10 individual runs in those series were duplicates). The other two duplicate runs were made with the slot hood at design exhaust rate. Table 5-2 presents precision results for each of the four sampling points monitored. This information indicates that the mannequin breathing zone measurements were highly variable. The enclosure exhaust and backroom sampling points were very consistent in that the average difference between duplicated measurements was 2 and 1 ppm, respectively. The average percent difference was relatively high at these two points because the gas concentration levels tended to be low. Only two duplicate test runs were made with LEV in place. The LEV exhaust concentration measurement pairs from these runs were relatively precise in that the average percent difference in the pairs was 5.8.

5.2 CONCLUSIONS

When operated at its ACGIH design flow rate, the canopy hood is highly effective in capturing emissions from a drum-filling operation. Capture efficiencies of 93 to 100 percent can be expected based on total emissions from the drum. The effectiveness of the canopy hood in reducing exposure of a drum-filling operator could not be reliably determined in this study.

The slot hood operated at its ACGIH design flow rate was highly effective in both reducing exposure to a mannequin and capturing emissions. Efficiency of the hood based on the reduction of mannequin exposure is 99 to 100 percent, while capture efficiency ranges from 95 to 100 percent. However, at a low exhaust flow rate (half of design), the slot hood was ineffective in reducing exposure and capturing emissions.

The lay-on hood was highly effective in reducing mannequin exposure and capturing emissions at both its ACGIH design exhaust rate and at one-seventh of its design rate. Efficiency of the hood in reducing exposure and capturing emissions is 100 percent at both exhaust rates.

In general, the efficiency of an LEV system for a drum-filling operation is independent of the concentration of emissions leaving the drum. The drum fill rate, which determines emission velocity at the drum bung hole, has been shown to affect LEV efficiency for the slot hood used in this study.

Table 5-2. Analysis of Duplicate Test Gas Concentration Measurements

Location	Number of duplicate pairs	Average difference of the paired measurements	
		ppm	percent
Mannequin breathing zone	12	40	39.1
Enclosure exhaust	12	2	17.3
Back room	12	1	23.3
LEV exhaust	2	10	5.8

5.3 RECOMMENDATIONS FOR FURTHER STUDY

- ° Perform similar experiments with different LEV designs. Industry information could be gathered on the types of LEV most often used with drum-filling operations to determine the hood types to be studied. In particular, hoods which fit onto drum-filling lances and operate at very low exhaust flow rates could be evaluated. A scavenging system such as that used on some gasoline fillers would also be a good candidate for testing.
- ° Perform LEV efficiency evaluations with different drum types, most notably, drums with fill and vent bung holes, open-top barrels, and clamp-top drums. Industry information could be gathered to determine common practices in drum-filling.
- ° Using the same facility, perform LEV effectiveness evaluations on different operations such as bag filling with a solid or a small degreasing operation.
- ° Characterize the effects of cross drafts on hood capture efficiency.

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1. Midwest Research Institute, Occupational Exposure Assessment, Draft Final Report, EPA Contract No. 68-02-3938, Work Assignment No. 10. (1985).
2. 40 CFR, Appendix A, Methods 1, 2, and 25A. (July 1986).
3. American Conference of Governmental Industrial Hygienists. Industrial Ventilation, 19th Edition. (1986). Canopy Hood, p. 4-18; Slot Hood, pp. 4-4 and 5-36; Lay-on Hood, p. 5-36.

APPENDIX A

ORIFICE METER CALIBRATION FOR
DRUM FILL RATE CONTROL

The orifice meter used to measure air flow to the drum (i.e., drum fill rate) was calibrated with a wet and a dry test meter. A pump pulled air through a standard wet test meter with its discharge leading directly to a dry test meter. The discharge of the dry test meter lead directly to the orifice where pressure drop was measured.

Both wet and dry test meters were used because the wet test meter was not able to measure flow rates over 2 cfm. Since a maximum flow of 3.34 cfm was required, a dry test meter (not as accurate as a wet test meter) was used to calibrate the orifice at higher flow rates.

Flow through the calibration system was adjusted by throttling inlet air flow to the pump with a needle valve. Air flow volume measured on the test meters was timed at various orifice pressure drop settings. This yielded data on flow rate versus orifice pressure drop. Using the temperatures of the wet and dry test meters and the barometric pressure, flow rates were converted to standard conditions.

Figure A-1 diagrams the results of the orifice calibration. The two drum fill rates used in the study (1.47 and 3.34 cfm) were maintained by setting the pressure drop of the orifice at 0.33 and 1.96 inches of H_2O , respectively.

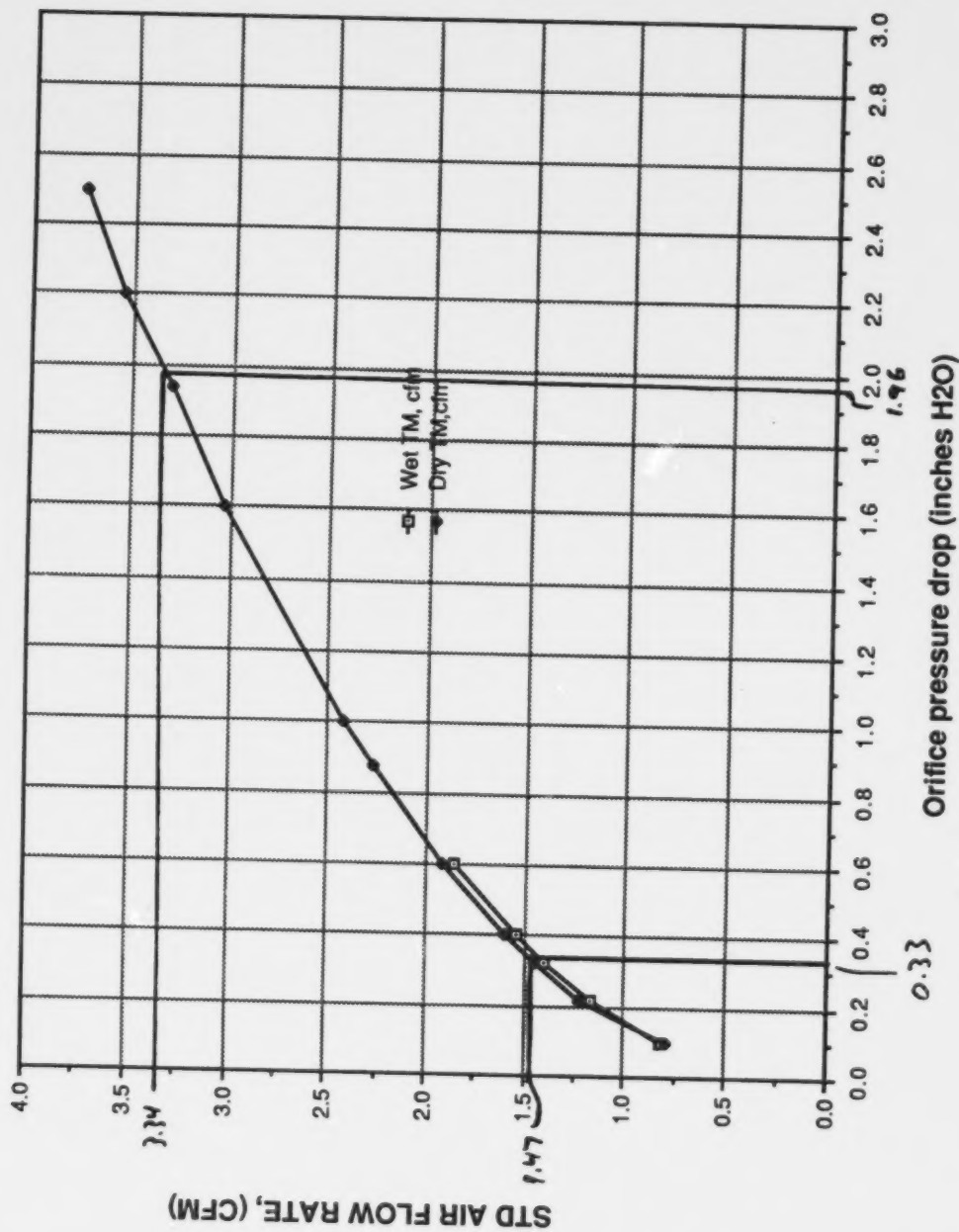


Figure A-1. Orifice calibration curve.

APPENDIX B

ROTAMETER CALIBRATION FOR
TEST GAS FEED RATE MEASUREMENT

Two rotameters ("small" and "large") were calibrated in order to measure and control test gas feed rate for the liquid drum filling simulation. To calibrate the rotameters, a bubble rate meter was used. Test gas from the storage cylinder was fed to the inlet of the "small" rotameter via a Teflon line. The outlet of the "small" rotameter led to the inlet of the "large" rotameter while the outlet of the "large" rotameter led to the bubble rate meter.

Both rotameters contained two flow indicating beads, one glass and the other steel. Each bead produced a separate flow calibration curve.

The "small" rotameter was calibrated with the flow control valve on the large rotameter fully open and vice versa. At numerous flow settings on the rotameters, the test gas flow rate through the bubble meter was timed producing data on rotameter setting versus test gas flow rate in actual cubic centimeters per minute. The test gas flow rates were converted to standard conditions and the calibration curves in Figures B-1 through B-3 constructed.

Desired test gas feed rates (Table 3-2) for the experimental study were converted from milligrams per second into standard centimeters per second using the molecular weight of the test gas and ideal gas equations. The desired test gas feed rate was then found on the rotameter calibration curves. The corresponding rotameter settings were then used to set and maintain the desired test gas feed rates during the study.

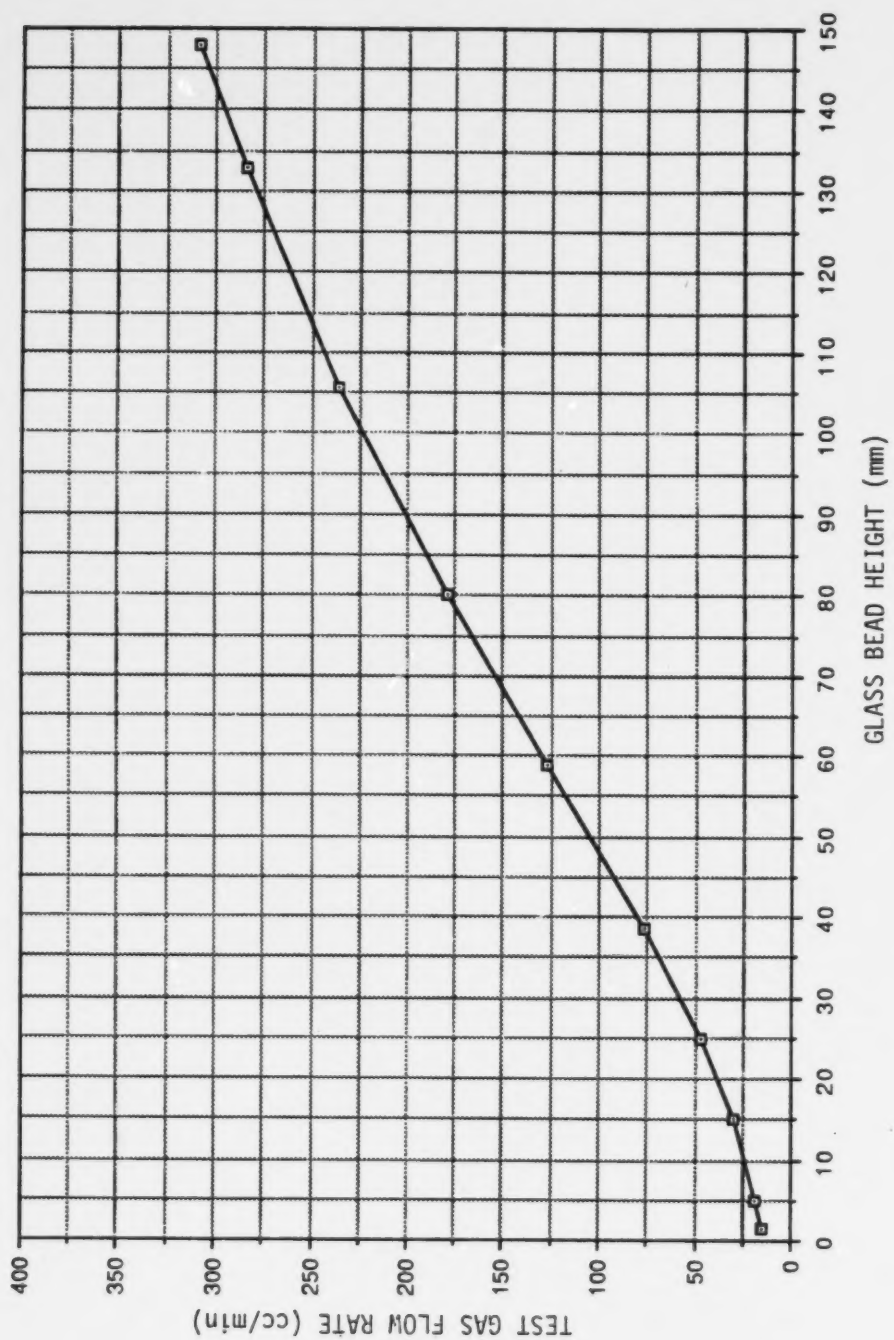


Figure B-1. Small rotometer calibration curve using glass bead.

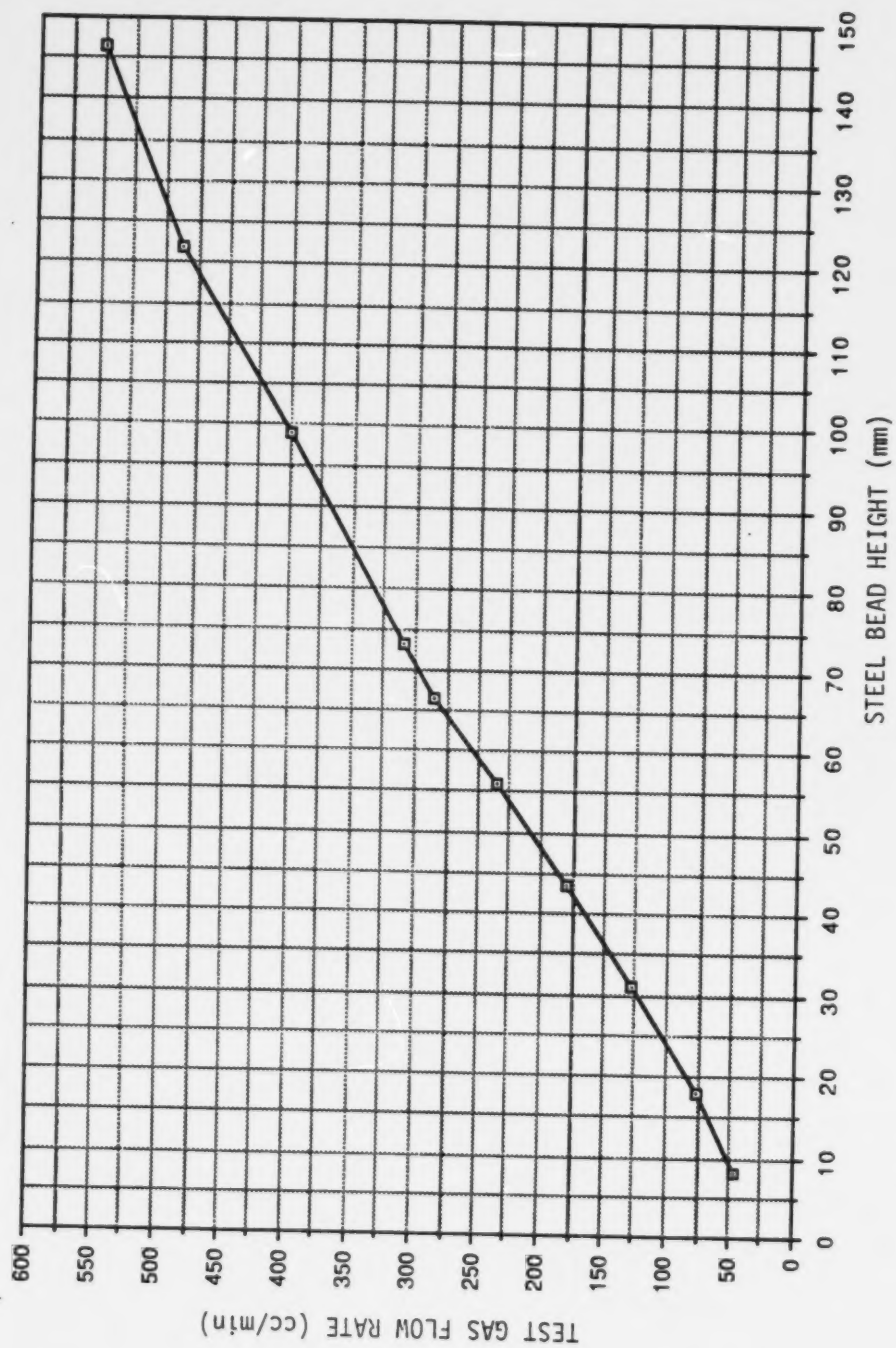


Figure B-2. Small rotometer calibration curve using steel bead.

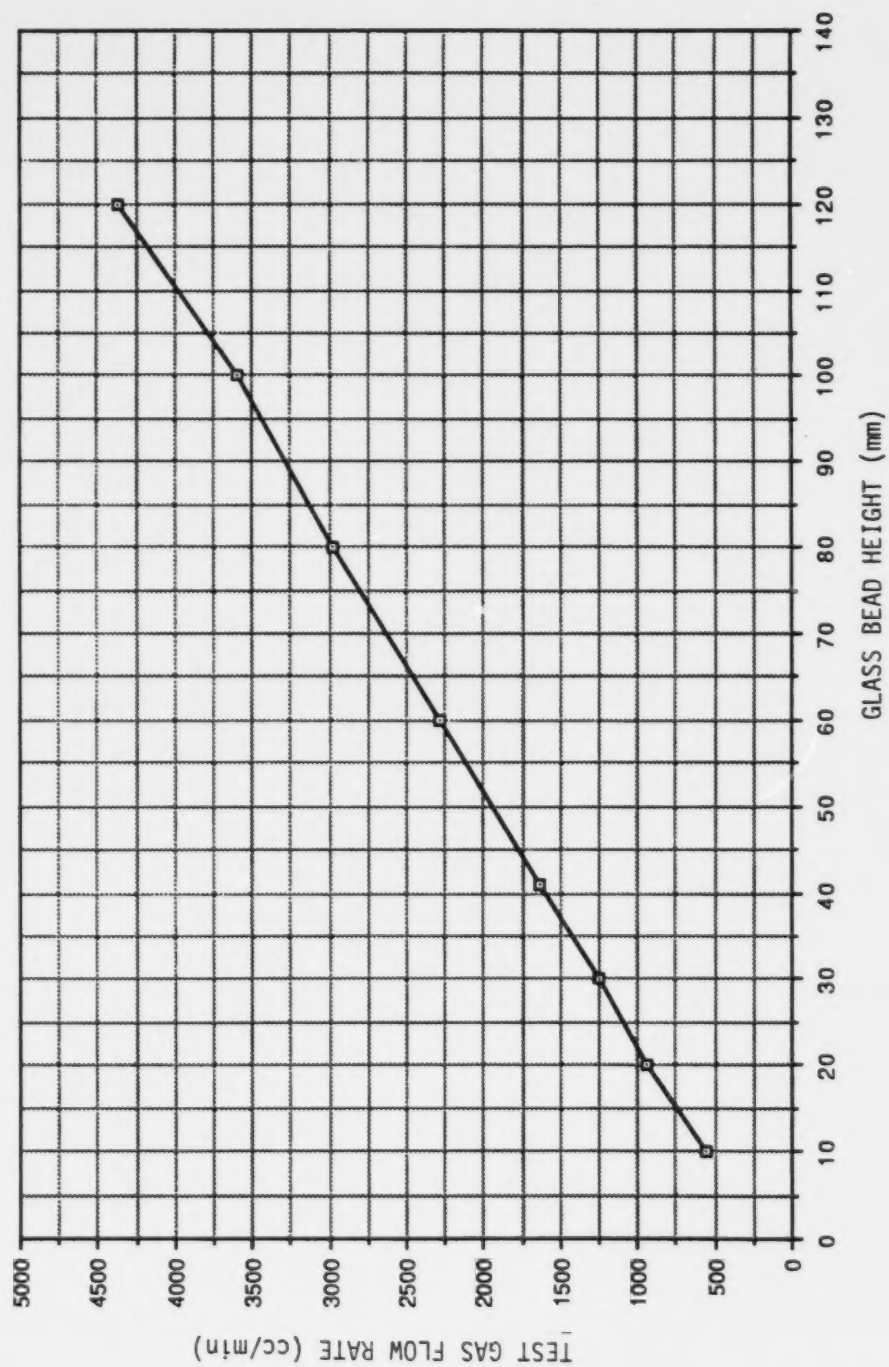


Figure B-3. Large rotometer calibration curve using glass bead.

APPENDIX C

PITOT TUBE TRAVERSES OF EXHAUST DUCTS
FOR MEASUREMENT OF EXHAUST FLOW RATE

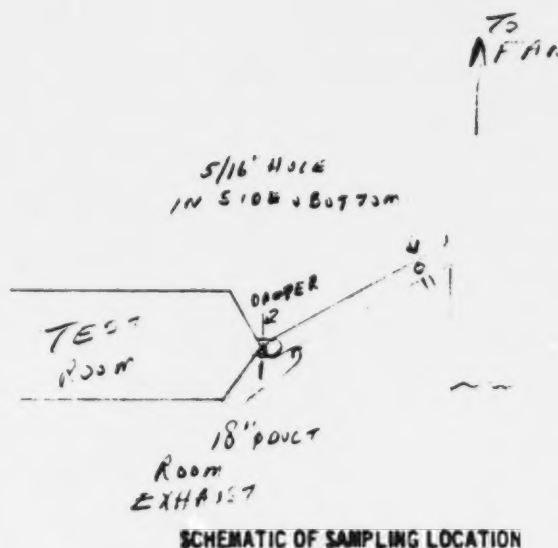
The following data was taken directly from pitot tube traverses of the exhaust ducts.

<u>Figure</u>	<u>Page</u>
Traverse point location worksheet for an 18 inch duct	C-3
Traverse data and calculation for air flow in the 18 inch main lab duct with only the enclosure exhaust branch open. Used for enclosure exhaust flow rate.	C-4
Traverse point location worksheet for 10 inch ducts	C-5
Traverse data and calculation for air flow in the 10 inch duct. Used with canopy hood at design flow.	C-6
Traverse point location worksheet for a 6 inch duct	C-7
Traverse data and calculation for air flow in the 6 inch duct. Used for the slot and lay-on hood at design flow rate.	C-8
Traverse data and calculation for air flow in the 6 inch duct. Used for the slot hood at low flow.	C-9
Traverse of the 6 inch duct using a hot-wire anemometer to directly measure velocity. This method was used for the lay-on hood at low flow. Flow was too low to measure with a pitot tube.	C-10

The air flow rate for the canopy hood at low flow was measured with the hot wire anemometer in the mid-point of the 10 inch duct (60 ft/min with 0.545 ft^2 yields 33 cfm). The measurement of 440 cfm for the canopy hood was made directly off of the manometer scale (cubic feet per minute versus pitot tube pressure differential in inches of H_2O) with the pitot tube at the centerline point of the 10 inch duct.

TRAVERSE POINT LOCATION FOR CIRCULAR DUCTS

Plant NIOSH
 Date 10-16-86
 Sampling location MAIN Room DUCT
 Inside of far wall to outside
 of nipple 18"
 Inside of near wall to outside of
 nipple (nipple length) 0
 Stack I.D. 18 IN.
 Nearest upstream disturbance 24" 1.33 dd
 Nearest downstream disturbance 93" 5.16 dd
 Calculated by R. OERSTLE



TRAVERSE POINT NUMBER	FRACTION OF STACK I.D.	STACK I.D.	PRODUCT OF COLUMNS 2 AND 3 (TO NEAREST 1/8 INCH)	NIPPLE LENGTH	TRAVERSE POINT LOCATION FROM OUTSIDE OF NIPPLE (SUM OF COLUMNS 4 & 5)
1	.032	18"	0.57	-	1"
2	.105		1.9		1.9
3	.194		3.5		3.5
4	.323		5.8		5.8
5	.677		12.2		12.2
6	.800		14.5		14.5
7	.895		16.1		16.1
8	.968		17.4		17.0
Center	.5		9.0		

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GAS VELOCITY AND VOLUMETRIC FLOW RATE

Plant and City NIOSH Date 11-3-86
Sampling Location 18" MAIN DUCT FOR LAB Clock Time 2:00 PM
Run No. 1 Operator DP / D. Osterhaus
Barometric Pressure, in. Hg 29.64 Static Pressure, in. H₂O -11.4
Moisture, % 1.65 Molecular wt., Dry 28.8 Pitot Tube, Cp 0.99
Stack Dimension, in. Diameter or Side 1 18" Side 2 18"

WGT BLB/Dr, B-LR = 65/77

FIELD DATA

TRAVERSE POINT NUMBER	VELOCITY MEAS. (cm^3/s , 100 mL) / $\sqrt{\Delta P}$	STACY TEMP., °F
V1	0.07 .285	77
2	0.08 .287	
3	0.09 .288	
4	0.08 .290	
5	0.09 .300	
6	0.08 .283	
7	0.08 .283	
8	0.07 .265	
H1	0.05 .274	
2	0.08 .283	
3	0.08 .283	
4	0.08 .283	
5	0.09 .300	
6	0.09 .300	
7	0.09 .300	
8	0.09 .300	
$\text{Avg } \sqrt{\Delta P} = .282$		

NOTE: Traveler paid \$5000
AS 10-16-86 Traveler
cf. main room 10-17.

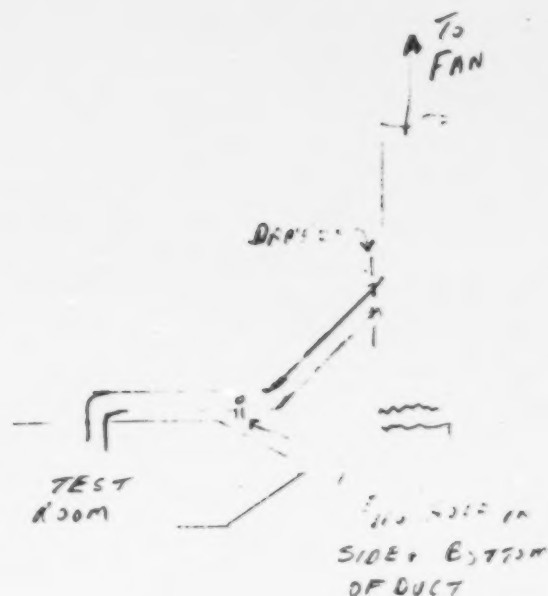
CALCULATIONS

$$\begin{aligned}
 M_1 &= M_0 = (1 - \frac{H_2O}{100}) \cdot 10 = (\frac{9}{100}) \\
 M_1 &= (28.8) = (1 - \frac{1.65}{100}) \cdot 10 = (\frac{1.65}{100}) \\
 M_1 &= 28.62 \\
 T_1 &= 77 \text{ } ^\circ\text{F} = 537 \text{ } ^\circ\text{R} = (^\circ\text{F} + 460) \\
 P_1 &= P_0 = \frac{P_0}{13.8} = (29.64) = \frac{11.4}{13.8} \\
 P_1 &= 28.80 \text{ in. Hg} \\
 \sqrt{v} &= 0.282 \\
 v_1 &= 85.49 = C_D = \sqrt{v} = \sqrt{\frac{T_1}{P_1} \cdot \frac{P_0}{T_0}} \\
 v_1 &= 85.49 = (0.99) = (282) = \sqrt{\frac{537}{28.80 \cdot 29.64}} \\
 v_1 &= 19.26 \checkmark \text{ ft/s} \\
 A_1 &= 1.767 \checkmark \text{ ft}^2 \\
 Q_1 &= v_1 \cdot A_1 = \frac{60}{s} \\
 Q_1 &= 19.26 \checkmark \cdot 1.767 = 60 \\
 Q_1 &= 2042 \text{ cfm} \\
 Q_{1std} &= Q_1 = 17.647 = \frac{P_1}{P_0} = (1 - \frac{H_2O}{100}) \\
 Q_{1std} &= 17.647 = (1 - \frac{H_2O}{100}) \\
 Q_{1std} &= 17.647 = (1 - \frac{H_2O}{100}) \\
 Q_{1std} &= 17.647 = (1 - \frac{H_2O}{100})
 \end{aligned}$$

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TRAVERSE POINT LOCATION FOR CIRCULAR DUCTS

Plant NIOSH
 Date 10-16-86
 Sampling location HOOD EXHAUST
 Inside of far wall to outside of nipple 10"
 Inside of near wall to outside of nipple (nipple length) ~0"
 Stack I.D. 10" LINE
 Nearest upstream disturbance dd
 Nearest downstream disturbance dd
 Calculated by R Ginter



SCHEMATIC OF SAMPLING LOCATION

TRAVERSE POINT NUMBER	FRACTION OF STACK I.D.	STACK I.D.	PRODUCT OF COLUMNS 2 AND 3 (TO NEAREST 1/8 INCH)	NIPPLE LENGTH	TRAVERSE POINT LOCATION FROM OUTSIDE OF NIPPLE (SUM OF COLUMNS 4 & 5)
1	.044	10"	0.44	-	0.5
2	.146		1.5		1.5
3	.296		3.0		3.0
4	.706		7.0		7.0
5	.854		8.5		8.5
6	.956		9.6		9.6
Center	.5		5.0		5.0

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GAS VELOCITY AND VOLUMETRIC FLOW RATE

Plant and City NIDH Date 10-24-86
Sampling Location LEV EXHAUST with CANOE Clock Time 3:50 PM
Run No. PRE 2 Operator R. GERTZKE
Barometric Pressure, in. Hg 29.63 Static Pressure, in. H₂O - [2.1 - 2.9] - 0.0
Moisture, % _____ Molecular wt., Dry 28.5 Pitot Tube, Cp 0.99
Stack Dimension, in. Diameter or Side 1 10" Side 2 -

W.C. 70th
C.C. 70

FIELD DATA

TRAVERSE POINT NUMBER	VELOCITY MEAS. (AD), IN. H. C.	STACY TEMP., °F
H = 1	1.30	1.16
2	1.35	1.24
3	1.35	1.25
4	1.35	1.13
5	1.35	1.12
6	1.15	1.20
7	1.30	-
V = 1	1.35	1.13
2	1.25	1.19
3	1.30	1.1
4	1.45	1.20
5	1.32	1.21
6	1.35	1.1
Q	1.30	-
	2	1.1
	1.1	1.1
		✓

CALCULATIONS

$$u_1 = 28.56$$

7. 80 7. 540 7. (7. 860)

$$P_1 \cdot P_2 \cdot \frac{P_3}{P_4} = (29.63) \cdot \frac{-6.0}{11.1}$$

29 19 1900

$\sqrt{25} = 1.149$

$$v_s = 85.49 \times 10^3 \times \sqrt{40} \times \sqrt{\frac{1.1 \times 10^9}{1.1 \times 10^9 + 1.1 \times 10^9}}$$

$$r_1 = 85.49 \times 10.99 \quad 1.11179 \quad 1.2 \sqrt{\frac{54.2}{29.19^2 \cdot 2.55}}$$

$v = 78.27 \text{ m/s}$

$A_0 = .5454$ 923

$$Q_1 = V_1 \times A_1 = \frac{60 \text{ l}}{\text{s}}$$

860

Q. 2561 acfn

$$Q_{s, \text{sig}} = Q_s \times 37.647 = \frac{5}{s} \times \left(1 - \frac{M_2 O^2}{100}\right)$$

$$Q_{\text{red}} = 2551 \times 17.647 \times \frac{27.19}{540} \times (1 - \frac{1.2}{100})$$

Q. 2314 - 2314 - 2314

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TRAVERSE POINT LOCATION FOR CIRCULAR DUCTS

Plant NIOSH
 Date 10/31/86
 Sampling location LEV EXHAUST
 Inside of far wall to outside of nipple 6"
 Inside of near wall to outside of nipple (nipple length) ~0
 Stack I.D. 6"
 Nearest upstream disturbance ~3 dd 17.5'
 Nearest downstream disturbance dd
 Calculated by RLB

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SCHEMATIC OF SAMPLING LOCATION

TRAVERSE POINT NUMBER	FRACTION OF STACK I.D.	STACK I.D.	PRODUCT OF COLUMNS 2 AND 3 (TO NEAREST 1/8 INCH)	NIPPLE LENGTH	TRAVERSE POINT LOCATION FROM OUTSIDE OF NIPPLE (SUM OF COLUMNS 4 & 5)
1	6.7	6"	0.402	0	0.5
2	2.5	↓	1.5	1	1.5
3	1.2	↓	0.5	1	4.5
4	1.2	↓	5.6	1	5.5

Desired flow 350 cfm $V_s = \frac{300}{\pi \times 6^2} = 1530 \text{ fpm}$

$\text{TAP} = \frac{1500}{60} \times \frac{1}{1530} \times \frac{1}{54} = 0.382$ or $\Delta P \sim 0.15" \text{ H}_2\text{O}$

GAS VELOCITY AND VOLUMETRIC FLOW RATE

Plant and City NIOSH

Date 10/3/86

Sampling Location SCOT HOOD - ENCLAVE

Clock Time 3:30 PM

Run No. PREL

Operator R6

Barometric Pressure, in.Hg 29.70

Static Pressure, in.H₂O -0.45

Moisture, % 1.2

Molecular wt., Dry 28.8

Pitot Tube, Cp 2.44

Stack Dimension, in. Diameter or Side 1

Side 2

DB 78°F

11E 63

1105 H
m. 11. 2-1
117-27 Top.

FIELD DATA

[illegible]

CALCULATIONS

$$M_3 = M_2 \times \left(1 - \frac{H_2O}{100}\right) + 18 \left(\frac{H_2O}{100}\right)$$

$$u_1 = (28.5) \cdot (1 - \frac{1.2}{100}) \cdot 10 (\frac{1.5}{100})$$

227

Y. 53⁵ R. (Y. 460)

$$P_1 \cdot P_2 \cdot \frac{S.P.}{15.6} \cdot (29.78) \cdot \frac{-0.45}{15.6} = 1.175$$

$P_3 =$ 1n.Wg

$\sqrt{2} \cdot$

$$V_s = 85.49 \times C_D \times \sqrt{\Delta P} \times \sqrt{\frac{7}{\frac{1}{\rho} \times \frac{1}{\mu}}}$$

$$V_s = 85.49 \times (0.99) \times (0.409) \times \sqrt{\frac{538}{2.1 \times 10^6}}$$

98/8

$A_1 = 0.196$ " "

$$Q_2 = V_2 = A_2 \times \frac{60}{s} = 27.43 \times 0.190 \times 60 = 312.5 \text{ cm}^3/s$$

0. 2 260

Q. 323 acfm

$$Q_{s, 87.6} = Q_s \times 17.647 \times \frac{P_s}{T_s} \times \left(1 - \frac{H_2O^s}{100}\right)$$

$$Q_{std} = 17.647 \times \left(1 - \frac{\text{---}}{100} \right)$$

03/11/2011 09:54:11

GAS VELOCITY AND VOLUMETRIC FLOW RATE

Plant and City NIOSH Date 11/17/80
Sampling Location 6" LEV Duct Clock Time 3:00pm
Run No. 1 Operator DP
Barometric Pressure, in. Hg 29.87 Static Pressure, in. H₂O -0.12
Moisture, % 1.2 Molecular wt., Dry 28.8 Pitot Tube, Cp 0.99
Stack Dimension, in. Diameter or Side 1 6" Side 2 6"

60°/77°f

FIELD DATA

TRAVEL POINT NUMBER	SPEED (MPH) IN AIR	V _P	STATION TEMP., °F
H 1	0.04	0.7	-
H 2	0.04	0.7	-
H 3	0.04	0.7	-
H 4	0.03	0.67	-
H C.L.	0.04	-	-
V 1	0.03	.173	-
V 2	0.04	.2	-
V 3	0.04	.2	-
V 4	0.04	.2	-
V C.L.	0.04	-	-
N/A			
		$\sqrt{A} = .193$	

CALCULATIONS

$$\begin{aligned}
 n_1 &= n_2 = (1 - \frac{n_2 \cdot 0}{100}) \cdot 39 (\frac{7 \cdot 0}{100}) \\
 n_1 &= (28.8) \cdot (1 - \frac{1.2}{100}) \cdot 39 (\frac{1.2}{100}) \\
 n_1 &= 28.67 \\
 T_1 &= 77 \text{ °F} = 537 \text{ °R} = (77 + 460) \\
 P_1 &= P_2 = \frac{F \cdot P}{13.6} = (29.87) \cdot \frac{0.12}{13.6} \\
 P_1 &= 29.86 \text{ in. Hg} \\
 V_{1D} &= 0.293 \\
 V_1 &= 85.49 \times CD = \sqrt{AP} = \sqrt{\frac{T_1 \cdot P_1 \cdot n_1}{P_2 \cdot T_2 \cdot n_2}} \\
 V_1 &= 85.49 \times (.99) \times (.193) = \sqrt{\frac{537}{29.86 \cdot 28.67}} \\
 V_1 &= 12.94 \text{ ft/s} \\
 A_1 &= .196 \text{ ft}^2 \\
 Q_1 &= V_1 \cdot A_1 = \frac{60 \cdot 3}{s} \\
 Q_1 &= \quad \quad \quad \times 60 \\
 Q_1 &= 152 \text{ acfm} \\
 Q_{1std} &= Q_1 \cdot 37.647 = \frac{P_1}{T_1} = (1 - \frac{n_2 \cdot 0}{100}) \\
 Q_{1std} &= 37.647 \times \quad \quad \quad = (1 - \frac{\quad}{100}) \\
 Q_{1std} &= \quad \quad \quad \text{acfm}
 \end{aligned}$$

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Velocity Traverse of 6-inch Duct with Hot-Wire Anemometer,
for the Lay-on Hold at Very Low Flow

Traverse point	Distance (in)	Ft/min
H1	0.5	230
H2	1.5	242
H3	4.5	220
H4	5.5	200
V1	0.5	200
V2	1.5	230
V3	4.5	230
V4	5.5	210

Average	220 fpm
Area	0.196 ft ²
cfm	43

APPENDIX D

EXAMPLE TEST RUN DATA FROM THE
FLAME IONIZATION DETECTOR

Figure D-1 presents the strip chart printout of a typical test run. This particular run was made with the lay-on hood at low air flow rate, the drum fill rate equal to 3.34 cfm, and the test gas feed rate equal to 80 mg/sec. The chart ran at a speed of 0.1 inches per minute and thus the entire test run took approximately 45 minutes.

This test run was started after completion of a test run at a higher test gas feed rate. As such the concentration of the LEV exhaust gradually declined until equilibrium was reached. After the LEV exhaust concentration measurement was made, the other sampling points were monitored. Because the test gas concentration was lower at these points than at the LEV exhaust, the attenuation of the FID was lowered ("A=1" designation as opposed to "A=500" for the LEV duct). Before the end of the run the LEV exhaust was monitored again to check if indeed, equilibrium had been reached. The concentration at each sampling point was determined using linear calibration plots developed from feeding known standards of test gas to the FID two or three times a day.

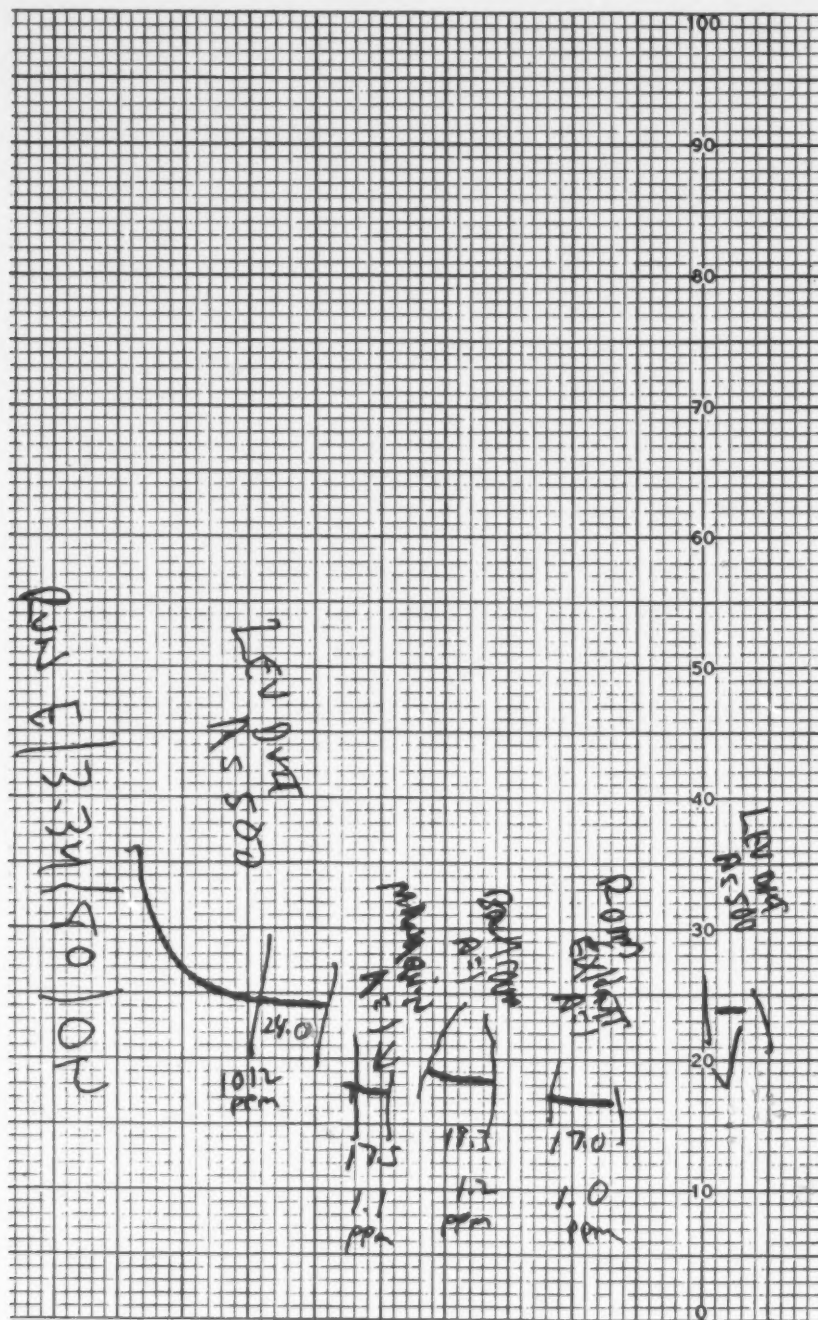


Figure D-1. FID strip chart print out of a typical test run.

APPENDIX E

RAW DATA

Raw data collected from the individual test runs are presented in the following tables. Calculated capture efficiencies and mass balance ratios are also presented. The raw data was transformed into final data using the following procedure:

- ° Test gas concentration levels measured at the five sampling points were adjusted for background levels detected with the FID. Raw concentration levels minus the background level yield the adjusted concentration level.
- ° Raw exhaust air flow rates were converted to standard conditions using the temperature and barometric pressure data.
- ° Test gas flow rates were calculated from the adjusted concentrations and the exhaust air flow rates at standard conditions.
- ° LEV capture efficiencies and mass balance ratios were calculated from the test gas flow rates.

Blank cells in the tables denote where concentration levels were not measured or where calculations could not be made because a concentration level was not measured.

Table E-1. Raw Monitoring Data - Test Series B, No LEV

Drum fill rate, cfm	Test gas feed rate, mg/sec	Concentration, ppm				
		Mannequin breathing zone	Enclosure exhaust	LEV exhaust	Back room	Front room
1.47	1	9	1	-	2	1
1.47	4	46	2	-	3	1
1.47	25	110	9	-	2	1
1.47	50	96	15	-	2	1
1.47	180	33	55	-	2	1
1.47	180	71	56	-	2	1
3.34	4	12	2	-	12	1
3.34	17	98	6	-	43	1
3.34	80	260	26	-	11	1
3.34	160	208	46	-	9	1
3.34	340	150	103	-	4	1
						Background

Table E-2. Adjusted Monitoring Data - Test Series B, No LEV

Drum fill rate, cfm	Test gas feed rate, mg/sec	Concentration, ppm				
		Mannequin breathing zone	Enclosure exhaust	LEV exhaust	Back room	Front room
1.47	1	8	0	-	1	0
1.47	4	45	1	-	2	0
1.47	25	109	8	-	1	0
1.47	50	95	14	-	1	0
1.47	180	32	54	-	1	0
1.47	180	70	55	-	1	0
3.34	4	11	1	-	11	0
3.34	17	97	5	-	42	0
3.34	80	259	25	-	10	0
3.34	160	207	45	-	8	0
3.34	340	149	102	-	3	0

Table E-3. Exhaust Rate Calculations - Test Series B, No LEV

Drum fill rate, cfm	Test gas feed rate, mg/sec	Enclosure exhaust rate, acfm	LEV exhaust rate, acfm	Barometric pressure, in. Hg	Temperature, °F	Enclosure exhaust rate, scfm	LEV exhaust rate, scfm
1.47	1	2042	-	29.53	78	1985	-
1.47	4	2042	-	29.53	78	1985	-
1.47	25	2042	-	29.53	78	1985	-
1.47	50	2042	-	29.53	78	1985	-
1.47	180	2042	-	29.53	78	1985	-
1.47	180	2042	-	29.79	77	2007	-
3.34	4	2042	-	29.79	77	2007	-
3.34	17	2042	-	29.79	77	2007	-
3.34	80	2042	-	29.79	77	2007	-
3.34	160	2042	-	29.79	77	2007	-
3.34	340	2042	-	29.79	77	2007	-

Table E-4. Mass Balance Calculations - Test Series B, No LEV

Drum fill rate, cfm	Test gas feed rate, mg/sec	Measured test gas rate, cc/min			Test gas feed rate, cc/min	Mass balance, ratio of test gas feed to measured rates
		In enclosure exhaust	In LEV exhaust	Total		
1.47	1	0	-	0	13	-
1.47	4	56	-	56	53	0.94
1.47	25	449	-	449	334	0.74
1.47	50	787	-	787	668	0.85
1.47	180	3034	-	3034	2407	0.79
1.47	180	3123	-	3123	2407	0.77
3.34	4	57	-	57	53	0.93
3.34	17	284	-	284	227	0.80
3.34	80	1420	-	1420	1070	0.75
3.34	160	2555	-	2555	2139	0.84
3.34	340	5792	-	5792	4546	0.78

Table E-5. Raw Monitoring Data - Test Series F, No LEV

Drum fill rate, cfm	Test gas feed rate, mg/sec	Mannequin breathing zone	Concentration, ppm			
			Enclosure exhaust	LEV exhaust	Back room	Front room
1.47	1	12	2	-	2	-
1.47	4	52	2	-	1	-
1.47	25	168	9	-	1	-
1.47	50	135	16	-	2	-
1.47	180	66	52	-	2	-
3.34	4	6	2	-	12	-
3.34	17	30	6	-	44	-
3.34	80	390	24	-	10	-
3.34	160	120	43	-	8	-
3.34	340	77	112	-	4	-
						Background
						0.9
						0.9
						0.9
						0.9
						0.9
						0.9
						0.9
						0.9
						0.9

Table E-6. Adjusted Monitoring Data - Test Series F, No LEV

Drum fill rate, cfm	Test gas feed rate, mg/sec	Concentration, ppm			
		Mannequin breathing zone	Enclosure exhaust	LEV exhaust	Front room
1.47	1	11	1	-	1
1.47	4	51	1	-	0.1
1.47	25	167	8	-	0.1
1.47	50	134	15	-	1
1.47	180	65	51	-	1
3.34	4	5	1	-	11
3.34	17	29	5	-	43
3.34	80	389	23	-	9
3.34	160	119	42	-	7
3.34	340	76	111	-	3

Table E-7. Exhaust Rate Calculations - Test Series F, No LEV

Drum fill rate, cfm	Test gas feed rate, mg/sec	Enclosure exhaust rate, acfm	LEV exhaust rate, acfm	Barometric pressure, in. Hg	Temperature, °F	Enclosure exhaust rate, scfm	LEV exhaust rate, scfm
1.47	1	2042	-	30.15	77	2031	-
1.47	4	2042	-	30.15	77	2031	-
1.47	25	2042	-	30.15	77	2031	-
1.47	50	2042	-	30.15	77	2031	-
1.47	180	2042	-	30.15	77	2031	-
3.34	4	2042	-	29.87	77	2012	-
3.34	17	2042	-	29.87	77	2012	-
3.34	80	2042	-	29.87	77	2012	-
3.34	160	2042	-	29.87	77	2012	-
3.34	340	2042	-	29.87	77	2012	-

Table E-8. Mass Balance Calculations - Test Series F, No LEV

Drum fill rate, cfm	Test gas feed rate, mg/sec	Measured test gas rate, cc/min			Test gas feed rate, cc/min	Mass balance, ratio of test gas feed to measured rates
		In enclosure exhaust	In LEV exhaust	Total		
1.47	1	57	-	57	13	0.23
1.47	4	57	-	57	53	0.92
1.47	25	460	-	460	334	0.73
1.47	50	862	-	862	668	0.77
1.47	180	2931	-	2931	2407	0.82
3.34	4	57	-	57	53	0.93
3.34	17	285	-	285	227	0.80
3.34	80	1310	-	1310	1070	0.82
3.34	160	2391	-	2391	2139	0.89
3.34	340	6320	-	6320	4546	0.72

Table E-9. Raw Monitoring Data - Test Series A, Canopy Hood at Design Air Flow

Drum fill rate, cfm	Test gas feed rate, mg/sec	Concentration, ppm				
		Mannequin breathing zone	Enclosure exhaust	LEV exhaust	Back room	Front room
1.47	4	1	1	2	2	1
1.47	25	0.9	0.7	6	0.9	0.9
1.47	50	2	1	10	1	2
1.47	80	1	1	15	2	2
1.47	340	1	0.9	68	1	1
3.34	17	1	1	4	1	-
3.34	80	1	1	16	1	-
3.34	340	1	1	65	1	-
						Background
						1
						1
						1
						1
						1
						1
						1
						1

Table E-10. Adjusted Monitoring Data - Test Series A, Canopy Hood at Design Air Flow

Drum fill rate, cfm	Test gas feed rate, mg/sec	Concentration, ppm			
		Mannequin breathing zone	Enclosure exhaust	LEV exhaust	Front room
1.47	4	0	0	1	0
1.47	25	0	0	5	0
1.47	50	1	0	9	1
1.47	80	0	0	14	1
1.47	340	0	0	67	0
3.34	17	0	0	3	0
3.34	80	0	0	15	0
3.34	340	0	0	64	0

Table E-11. Exhaust Rate Calculations - Test Series A, Canopy Hood at Design Air Flow

Drum fill rate, cfm	Test gas feed rate, mg/sec	Enclosure exhaust rate, acfm	LEV exhaust rate, acfm	Barometric pressure, in. Hg	Temperature, °F	Enclosure exhaust rate, scfm	LEV exhaust rate, scfm
1.47	4	2042	2561	29.61	77	1995	2501
1.47	25	2042	2561	29.61	77	1995	2501
1.47	50	2042	2561	29.61	77	1995	2501
1.47	80	2042	2561	29.67	78	1995	2502
1.47	340	2042	2561	29.61	77	1995	2501
3.34	17	2042	2561	29.67	78	1995	2502
3.34	80	2042	2561	29.67	78	1995	2502
3.34	340	2042	2561	29.67	78	1995	2502

Table E-12. Mass Balance Calculations - Test Series A, Canopy Hood at Design Air Flow

Drum fill rate, cfm	Test gas feed rate, mg/sec	Measured test gas rate, cc/min			Test gas feed rate, cc/min	Mass balance, ratio of test gas feed to measured rates	LEV capture efficiency, percent	
		In enclosure exhaust	In LEV exhaust	Total			Based on test gas feed rate	Based on test gas output rate
1.47	4	0	71	71	53	0.75	130	100
1.47	25	0	354	354	334	0.94	110	100
1.47	50	0	637	637	668	1.05	95	100
1.47	80	0	991	991	1070	1.08	93	100
1.47	340	0	4743	4743	4546	0.96	100	100
3.34	17	0	212	212	227	1.07	94	100
3.34	80	0	1062	1062	1072	1.01	99	100
3.34	340	0	4531	4531	4553	1.00	100	100

Table E-13. Raw Monitoring Data - Test Series A, Canopy Hood at Low Air Flow

Drum fill rate, cfm	Test gas feed rate, mg/sec	Mannequin breathing zone	Concentration, ppm				
			Enclosure exhaust	LEV exhaust	Back room	Front room	Background
1.47	1	0.8	1	-	-	1	1
1.47	4	1	3	-	3	2	1
1.47	25	0.9	10	-	8	1	1
1.47	50	1	15	-	3	2	1
1.47	80	0.8	22	-	-	-	1
1.47	340	1	105	-	4	1	1
3.34	17	1	2	-	13	-	1
3.34	80	4	-	-	-	-	1
3.34	340	4	-	-	-	-	1
3.34	80	1	1	-	-	-	1
3.34	340	1	1	-	-	-	1

Table E-14. Adjusted Monitoring Data - Test Series A, Canopy Hood at Low Air Flow

Drum fill rate, cfm	Test gas feed rate, mg/sec	Concentration, ppm			
		Mannequin breathing zone	Enclosure exhaust	LEV exhaust	Front room
1.47	1	0	0	-	0
1.47	4	0	2	-	1
1.47	25	0	9	-	0
1.47	50	0	14	-	1
1.47	80	0	21	-	-
1.47	340	0	104	-	0
3.34	17	0	1	-	-
3.34	80	3	-	-	-
3.34	340	3	-	-	-
3.34	80	0	0	-	-
3.34	340	0	0	-	-

Table E-15. Exhaust Rate Calculations - Test Series A, Canopy Hood at Low Air Flow

Drum fill rate, cfm	Test gas feed rate, mg/sec	Enclosure exhaust rate, acfm	LEV exhaust rate, acfm	Barometric pressure, in. Hg	Temperature, °F	Enclosure exhaust rate, scfm	LEV exhaust rate, scfm
1.47	1	2042	33	29.67	78	1995	32
1.47	4	2042	33	29.61	77	1995	32
1.47	25	2042	33	29.61	77	1995	32
1.47	50	2042	33	29.61	77	1995	32
1.47	80	2042	33	29.67	78	1995	32
1.47	340	2042	33	29.61	77	1995	32
3.34	17	2042	33	29.67	78	1995	32
3.34	80	2042	33	29.67	78	1995	32
3.34	340	2042	33	29.67	78	1995	32
3.34	80	2042	440	29.67	78	1995	430
3.34	340	2042	440	29.67	78	1995	430

Table E-16. Mass Balance Calculations - Test Series A, Canopy Hood at Low Air Flow

Drum fill rate, cfm	Test gas feed rate, mg/sec	Measured test gas rate, cc/min			Test gas feed rate, cc/min	Mass balance, ratio of test gas feed to measured rates	LEV capture efficiency, percent	
		In enclosure exhaust	In LEV exhaust	Total			Based on test gas feed rate	Based on test gas output rate
1.47	1	0	-	-	13	-	-	-
1.47	4	87	-	-	53	-	-	-
1.47	25	391	-	-	334	-	-	-
1.47	50	609	-	-	668	-	-	-
1.47	80	913	-	-	1070	-	-	-
1.47	340	4522	-	-	4546	-	-	-
3.34	17	43	-	-	227	-	-	-
3.34	80	-	-	-	1072	-	-	-
3.34	340	-	-	-	4553	-	-	-
3.34	80	0	-	-	1072	-	-	-
3.34	340	0	-	-	4553	-	-	-

Table E-17. Raw Monitoring Data - Test Series C, Slot Hood at Design Air Flow

Drum fill rate, cfm	Test gas feed rate, mg/sec	Concentration, ppm				
		Mannequin breathing zone	Enclosure exhaust	LEV exhaust	Back room	Front room
1.47	1	0.9	1	3	1	1
1.47	4	2	1	6	2	1
1.47	25	1	1	39	2	1
1.47	50	1	1	77	1	1
1.47	180	2	1	283	2	1
1.47	180	1	1	275	1	2
3.34	4	1	1	6	1	1
3.34	17	1	1	26	1	1
3.34	80	2	2	126	2	1
3.34	80	2	1	117	2	2
3.34	160	2	2	237	2	1
3.34	340	1	1	546	1	1

Table E-18. Adjusted Monitoring Data - Test Series C, Slot Hood at Design Air Flow

Drum fill rate, cfm	Test gas feed rate, mg/sec	Concentration, ppm			
		Mannequin breathing zone	Enclosure exhaust	LEV exhaust	Front room
1.47	1	0	0	2	0
1.47	4	1	0	5	1
1.47	25	0	0	38	1
1.47	50	0	0	76	0
1.47	180	1	0	282	1
1.47	180	0	0	273	0
3.34	4	0	0	5	0
3.34	17	0	0	25	0
3.34	80	1	1	125	1
3.34	80	0	0	115	0
3.34	160	1	1	236	1
3.34	340	0	0	545	0

Table E-19. Exhaust Rate Calculations - Test Series C, Slot Hood at Design Air Flow

Drum fill rate, cfm	Test gas feed rate, mg/sec	Enclosure exhaust rate, acfm	LEV exhaust rate, acfm	Barometric pressure, in. Hg	Temperature, °F	Enclosure exhaust rate, scfm	LEV exhaust rate, scfm
1.47	1	2042	323	29.68	78	1995	316
1.47	4	2042	323	29.68	78	1995	316
1.47	25	2042	323	29.68	78	1995	316
1.47	50	2042	323	29.68	78	1995	316
1.47	180	2042	323	29.64	78	1993	315
1.47	180	2042	323	29.40	78	1977	313
3.34	4	2042	323	29.68	78	1995	316
3.34	17	2042	323	29.68	78	1995	316
3.34	80	2042	323	29.64	78	1993	315
3.34	80	2042	323	29.40	78	1977	313
3.34	160	2042	323	29.68	78	1995	316
3.34	340	2042	323	29.64	78	1993	315

Table E-20. Mass Balance Calculations - Test Series C, Slot Hood at Design Air Flow

Drum fill rate, cfm	Test gas feed rate, mg/sec	Measured test gas rate, cc/min			Test gas feed rate, cc/min	Mass balance, ratio of test gas feed to measured rates	LEV capture efficiency, percent	
		In enclosure exhaust	In LEV exhaust	Total			Based on test gas feed rate	Based on test gas output rate
1.47	1	0	18	18	13	0.73	140	100
1.47	4	0	45	45	53	1.19	84	100
1.47	25	0	339	339	334	0.98	100	100
1.47	50	0	679	679	668	0.98	100	100
1.47	180	0	2516	2516	2407	0.96	100	100
1.47	180	0	2416	2416	2407	1.00	100	100
3.34	4	0	45	45	53	1.19	84	100
3.34	17	0	223	223	227	1.02	98	100
3.34	80	56	1115	1171	1070	0.91	100	95
3.34	80	0	1018	1018	1070	1.05	95	100
3.34	160	56	2108	2165	2139	0.99	99	97
3.34	340	0	4862	4862	4546	0.94	110	100

Table E-21. Raw Monitoring Data - Test Series G, Slot Hood at Low Air Flow

Drum fill rate, cfm	Test gas feed rate, mg/sec	Concentration, ppm				
		Mannequin breathing zone	Enclosure exhaust	LEV exhaust	Back room	Front room
1.47	1	1	1	4	1	-
1.47	4	2	1	14	1	-
1.47	25	3	1	81	1	-
1.47	50	8	3	169	1	-
1.47	180	6	24	390	1	-
3.34	4	19	2	11	2	-
3.34	17	61	3	31	2	-
3.34	80	220	7	220	4	-
3.34	160	100	6	520	2	-
3.34	340	73	24	820	1	-
						Background
						1
						1
						0.9
						1
						1
						1
						0.9
						0.9
						1

Table E-22. Adjusted Monitoring Data - Test Series G, Slot Hood at Low Air Flow

Drum fill rate, cfm	Test gas feed rate, mg/sec	Concentration, ppm			
		Mannequin breathing zone	Enclosure exhaust	LEV exhaust	Front room
1.47	1	0	0	3	-
1.47	4	1	0	13	-
1.47	25	2	0.1	80	-
1.47	50	7	2	168	-
1.47	180	5	23	389	-
3.34	4	18	1	10	-
3.34	17	60	2	30	-
3.34	80	219	6	219	-
3.34	160	99	5	519	-
3.34	340	72	23	819	-
				0	-

Table E-23. Exhaust Rate Calculations - Test Series G, Slot Hood at Low Air Flow

Drum fill rate, cfm	Test gas feed rate, mg/sec	Enclosure exhaust rate, acfm	LEV exhaust rate, acfm	Barometric pressure, in. Hg	Temperature, °F	Enclosure exhaust rate, scfm	LEV exhaust rate, scfm
1.47	1	2042	152	29.50	77	1987	148
1.47	4	2042	152	29.50	77	1987	148
1.47	25	2042	152	29.87	77	2012	150
1.47	50	2042	152	29.50	77	1987	148
1.47	180	2042	152	29.50	77	1987	148
3.34	4	2042	152	29.50	77	1987	148
3.34	17	2042	152	29.50	77	1987	148
3.34	80	2042	152	29.87	77	2012	150
3.34	160	2042	152	29.87	77	2012	150
3.34	340	2042	152	29.50	77	1987	148

Table E-24. Mass Balance Calculations - Test Series G, Slot Hood at Low Air Flow

Drum fill rate, cfm	Test gas feed rate, mg/sec	Measured test gas rate, cc/min			Test gas feed rate, cc/min	Mass balance, ratio of test gas feed to measured rates	LEV capture efficiency, percent	
		In enclosure exhaust	In LEV exhaust	Total			Based on test gas feed rate	Based on test gas output rate
1.47	1	0	13	13	13	1.04	97	100
1.47	4	0	54	54	53	0.97	100	100
1.47	25	6	339	345	334	0.97	100	98
1.47	50	112	703	816	668	0.82	110	86
1.47	180	1293	1628	2922	2407	0.82	68	56
3.34	4	56	42	98	53	0.54	79	43
3.34	17	112	126	238	227	0.95	55	53
3.34	80	342	928	1270	1070	0.84	87	73
3.34	160	285	2200	2484	2139	0.86	100	89
3.34	340	1293	3428	4722	4546	0.96	75	73

Table E-25. Raw Monitoring Data - Test Series D, Lay-on Hood at Design Air Flow

Drum fill rate, cfm	Test gas feed rate, mg/sec	Mannequin breathing zone	Concentration, ppm			
			Enclosure exhaust	LEV exhaust	Back room	Front room
1.47	50	2	1	81	-	-
3.34	160	1	1	257	2	-
3.34	340	1	1	551	2	-
						Background
						1
						1
						1

Table E-26. Adjusted Monitoring Data - Test Series D, Lay-on Hood at Design Air Flow

Drum fill rate, cfm	Test gas feed rate, mg/sec	Concentration, ppm			
		Mannequin breathing zone	Enclosure exhaust	LEV exhaust	Front room
1.47	50	1	0	80	-
3.34	160	0	0	256	1
3.34	340	0	0	550	1

Table E-27. Exhaust Rate Calculations - Test Series D, Lay-on Hood at Design Air Flow

Drum fill rate, cfm	Test gas feed rate, mg/sec	Enclosure exhaust rate, acfm	LEV exhaust rate, acfm	Barometric pressure, in. Hg	Temperature, °F	Enclosure exhaust rate, scfm	LEV exhaust rate, scfm
1.47	50	2042	323	29.56	78	1987	314
3.34	160	2042	323	29.56	78	1987	314
3.34	340	2042	323	29.56	78	1987	314

Table E-28. Mass Balance Calculations - Test Series D, Lay-on Hood at Design Air Flow

Drum fill rate, cfm	Test gas feed rate, mg/sec	Measured test gas rate, cc/min			Test gas feed rate, cc/min	Mass balance, ratio of test gas feed to measured rates	LEV capture efficiency, percent	
		In enclosure exhaust	In LEV exhaust	Total			Based on test gas feed rate	Based on test gas output rate
1.47	50	0	712	712	668	0.94	110	100
3.34	160	0	2278	2278	2139	0.94	110	100
3.34	340	0	4893	4893	4546	0.93	110	100

Table E-29. Raw Monitoring Data - Test Series E, Lay-on Hood at Low Air Flow

Drum fill rate, cfm	Test gas feed rate, mg/sec	Concentration, ppm				
		Mannequin breathing zone	Enclosure exhaust	LEV exhaust	Back room	Front room
1.47	50	1	1	660	1	-
3.34	80	1	1	1012	1	-
3.34	160	1	1	2086	1	-
3.34	340	1	1	3407	1	-
						Background
						1
						1
						1
						1

Table E-30. Adjusted Monitoring Data - Test Series E, Lay-on Hood at Low Air Flow

Drum fill rate, cfm	Test gas feed rate, mg/sec	Concentration, ppm			
		Mannequin breathing zone	Enclosure exhaust	LEV exhaust	Front room
1.47	50	0	0	659	0
3.34	80	0	0	1011	0
3.34	160	0	0	2085	0
3.34	340	0	0	3406	0

Table E-31. Exhaust Rate Calculations - Test Series E, Lay-on Hood at Low Air Flow

Drum fill rate, cfm	Test gas feed rate, mg/sec	Enclosure exhaust rate, acfm	LEV exhaust rate, acfm	Barometric pressure, in. Hg	Temperature, °F	Enclosure exhaust rate, scfm	LEV exhaust rate, scfm
1.47	50	2042	43	29.67	77	1999	42
3.34	80	2042	43	29.67	77	1999	42
3.34	160	2042	43	29.67	77	1999	42
3.34	340	2042	43	29.67	77	1999	42

Table E-32. Mass Balance Calculations - Test Series E, Lay-on Hood at Low Air Flow

Drum fill rate, cfm	Test gas feed rate, mg/sec	Measured test gas rate, cc/min			Test gas feed rate, cc/min	Mass balance, ratio of test gas feed to measured rates	LEV capture efficiency, percent	
		In enclosure exhaust	In LEV exhaust	Total			Based on test gas feed rate	Based on test gas output rate
1.47	50	0	785	785	668	1	120	100
3.34	80	0	1204	1204	1070	0.89	110	100
3.34	160	0	2483	2483	2139	0.86	120	100
3.34	340	0	4057	4057	4546	1.12	89	100

APPENDIX F
DETAILED DIAGRAMS OF LEV HOODS

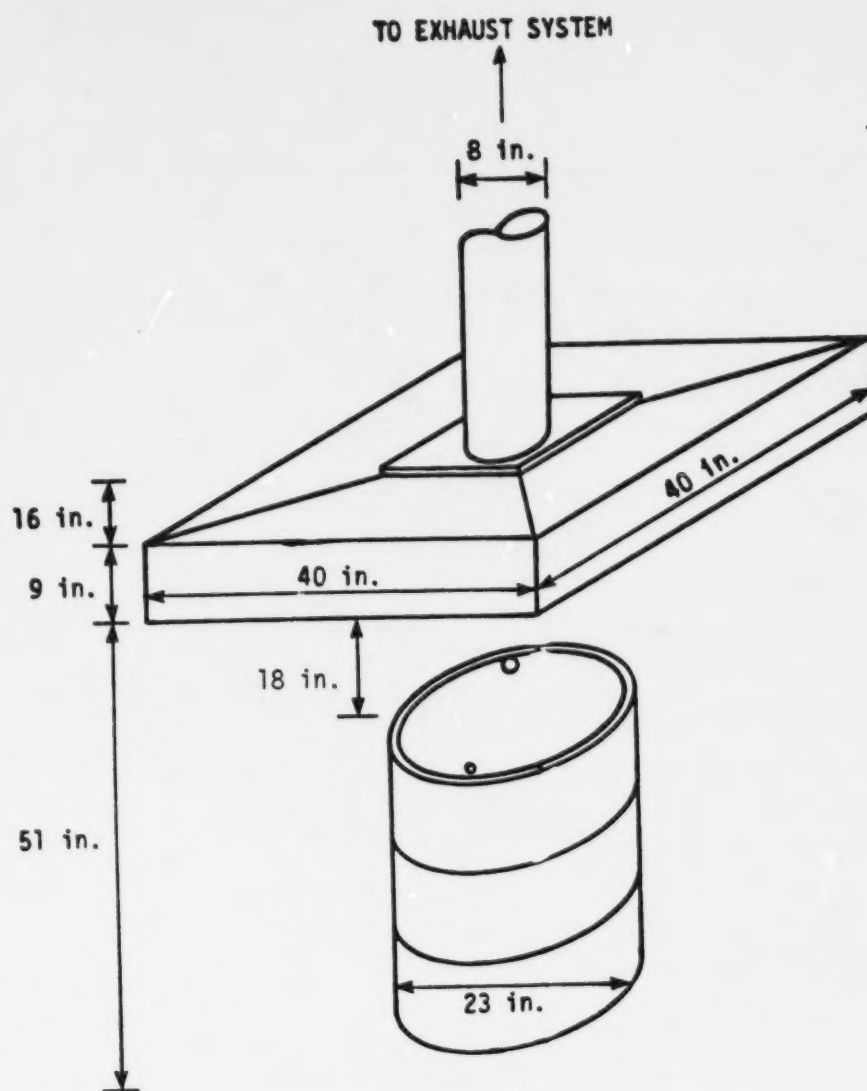
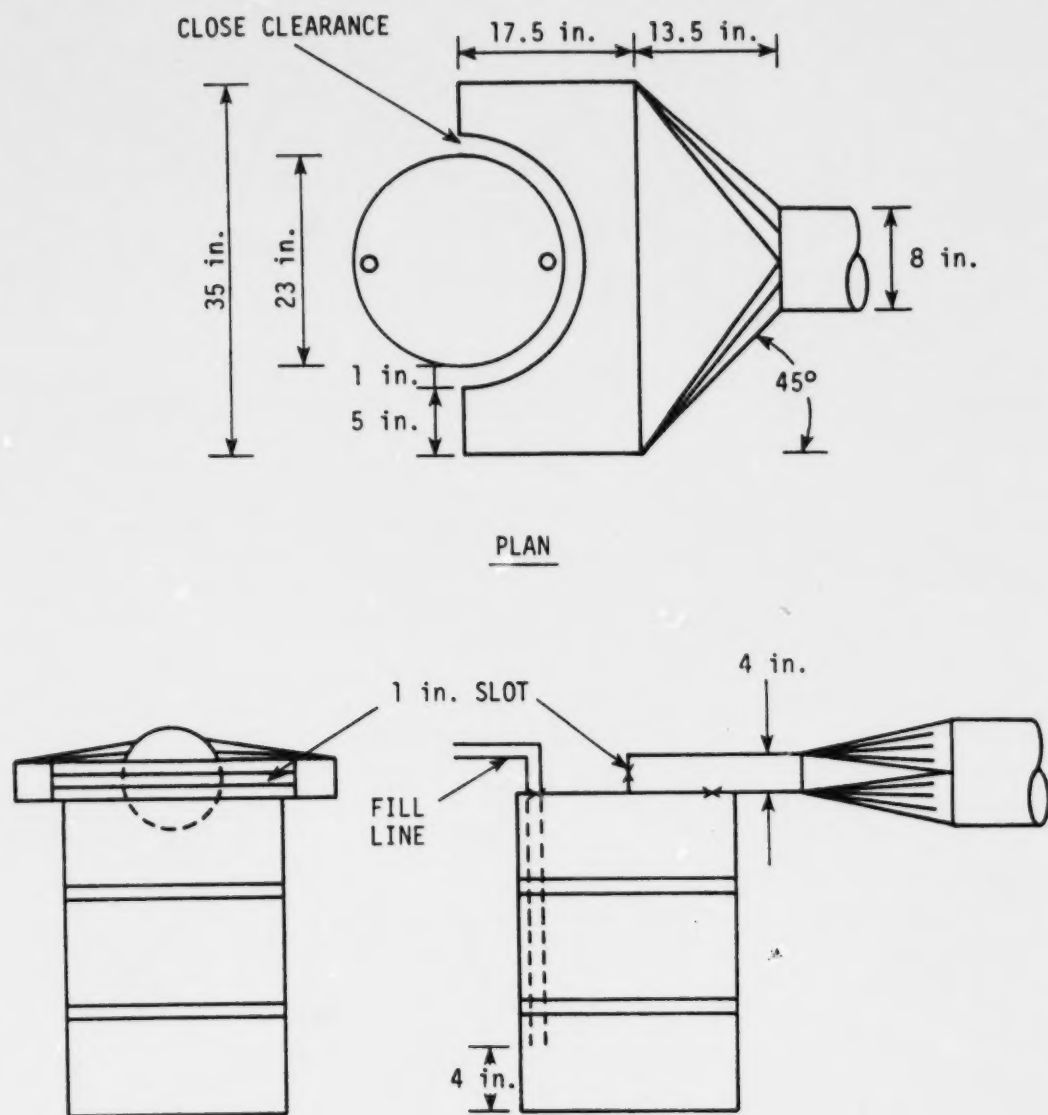


Figure F-1. Canopy hood.



PLAN

Figure F-2. Slot hood.

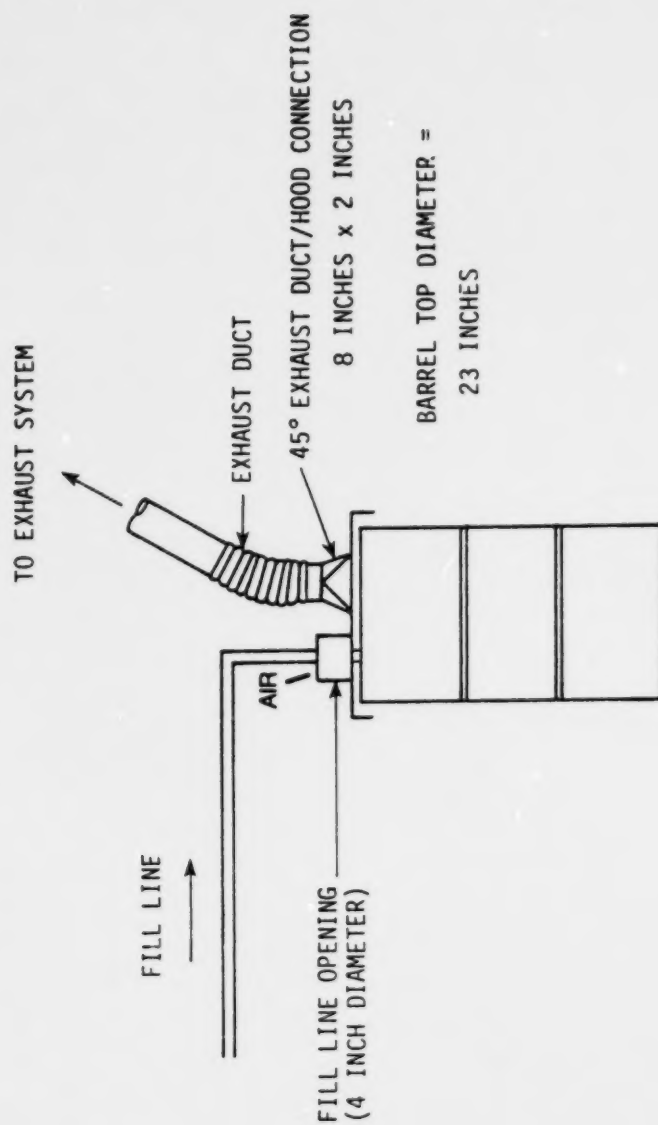


Figure F-3. Lay-on hood.

APPENDIX G
QUALITY ASSURANCE PROCEDURES

QUALITY ASSURANCE PROCEDURES

G.1 BACKGROUND

Objective

The purpose of this project was to experimentally determine the effectiveness of local exhaust ventilation (LEV) systems in reducing airborne pollutants from the breathing zone of workers. These pollutants were emitted from simulated drum filling operations.

These data will be used by the Chemical Engineering Branch (CEB) when evaluating an LEV unit's effectiveness for a drumming operation in reducing a worker's exposure to a PMN chemical. For CEB's purposes, the required precision in the effectiveness data is 1 to 2 significant figures (e.g., knowing that an LEV unit produces a 10-fold reduction in the airborne concentration at the worker's breathing zone is sufficient).

Experimental Design and Procedure

This objective was accomplished by injecting measured amounts of selected mixtures of air and a test gas of difluorochloroethane* into the bottom of a 55-gallon drum and measuring the test gas concentration at the breathing height near the drum and in the LEV exhaust duct. The test gas injected into the drum bottom exited the drum through the bung hole. This method of simulating drum filling emissions provided a safe and harmless method of testing LEV system effectiveness and was selected in lieu of pumping actual volatile liquids into drums which presented both explosion and health effects problems.

Three exhaust ventilation systems were evaluated at two exhaust rates each (one based on ACGIH recommendations for the system and the other determined based on preliminary results). The LEV systems evaluated were a slot hood, a canopy hood, and a lay-on hood.

* Pennwalt Corporation trade name is Isotron 142B; $\text{CH}_2\text{-C Cl F}_2$.

Two rates of air injection were used to simulate two drum filling rates and various amounts of test gas will be added as shown in Table G-1. The entire drum and LEV system were placed in a rectangular room 8' wide x 8' high x 16' long to prevent any unwanted drafts from effecting the LEV system. A slow (30 to 50 feet/minute) air flow was drawn through this room to prevent a buildup of test gas in the test area and to better simulate conditions found in industry and eliminate room size as a variable.

TABLE G-1. AIR AND TEST GAS RATES INJECTED INTO 55-GALLON DRUM

Test gas rate, mg/s ^a	Air inlet rate, cfm	Concentration, ppm ^b
340	3.34 (25 gpm)	51,810
180	1.47 (11 gpm)	62,320
160	3.34	24,380
50	1.47	17,310
80	3.34	12,190
25	1.47	8,655
17	3.34	2,590
4	1.47	1,385
4	3.34	609
1	1.47	346

^a Based on emissions measured by MRI and presented in their report entitled Occupational Exposure Assessment, Midwest Research Institute, EPA Contract 68-02-3938, Assignment 10, November 26, 1985. Pg. 70.

^b Parts per million by volume at bung hole after about 5 minutes using CH₃-CClF₂. Note that measurements of airborne concentration will be made after considerable dilution in ambient air and are not expected to exceed 10,000 ppm.

To measure test gas concentrations, a Beckman Model 402 flame ionization detector (FID) was used. This instrument had a range of 1 ppm to 10,000 ppm, was calibrated with known mixtures of test gas in air, and zeroed with nitrogen at the start and end of each day and halfway through the day's tests. This instrument had an electronic stability of one percent of span over a 24-hour period and a reproducibility of one percent of span for identical injections. A sampling manifold was used to allow sampling at either the breathing height, in the exhaust duct, and two other locations in the room.

Air flow in the exhaust duct was measured with a pitot tube and inclined manometer. The air flow into the drum was measured with a calibrated orifice and the test gas rate was measured with a calibrated rotometer.

To conduct a test, the room exhaust was started with all equipment in place. The air injection was started and set to the desired rate and the test gas was started and set at its desired rate. Room air concentrations of test gas were monitored and recorded with the FID. After the room air test gas concentration became constant, the LEV system was started and its exhaust flow carefully set and measured. Room air concentrations were measured again after concentrations leveled off. The test gas concentration in the LEV exhaust duct was also measured at that time.

This procedure was repeated for each test condition for each LEV system type. Duplicate runs of 10 percent of the tests were made. Data analysis consisted of comparing the breathing zone test gas concentration with the LEV system turned on to the concentration with the system turned off at the various gas/air injection rates. This fraction was an indication of LEV effectiveness.

In addition, the LEV effectiveness was computed by dividing the amount of test gas in the LEV system exhaust duct by the amount of test gas injected into the drum.

G.2 FACILITIES, EQUIPMENT, CONSUMABLES AND SERVICES

Facilities and Equipment

Site--

This work was conducted at the NIOSH ventilation research facility at 5555 Ridge Avenue, Cincinnati, Ohio. This facility contained a 10,000-cfm exhaust fan and duct system which could be tapped into for this assignment. The drum filling simulation and LEV system were placed in a newly constructed 8' wide x 8' high x 16' long enclosure. This enclosure was open at one end, and contained a room exhaust at the opposite end which maintained a slow air flow (30-50 fpm) through the enclosure. This enclosure prevented stray drafts from affecting the hood and also exhausted any test gas that was not captured by the LEV system. Figure 3-1 shows this enclosure and the duct-work.

Flow Measurement--

The gas flows in the LEV and room exhaust ducts were determined by measuring the velocity head with a standard type pitot tube and traversing the duct cross section along two orthongonal diameters according to procedures in EPA Method 1 and 2 (40 CFR Part 60, Subpart A). Center point velocity heads were measured and used to monitor the gas flow during the experimental work. Once the exhaust flow was set with the duct damper, it was not expected to change, but it was monitored. The velocity head was manually read on inclined manometer. The air flow temperature, which was room temperature, was read with mercury in glass thermometer and the gas gauge pressure was measured with an inclined manometer. Moisture in the air was ambient humidity and was measured with a sling psychrometer.

The test gas was purchased in pure form from Pennwalt Corporation in compressed gas cylinders. This gas was metered through a calibrated rotometer into the air line leading to the bottom of the drum. The rotometer was calibrated with the test gas and a bubble rate meter.

The air flow entering the drum was room air pumped through an orifice meter which was calibrated with a wet test meter over the flow range of 1 to 2 cfm and a dry test meter from 2 to 4 cfm. The orifice pressure drop was manually read with an inclined manometer. The orifice was located downstream from the pump and about 5 feet from the pump to allow the air to cool and be metered at ambient (room) temperature.

Gas Concentration Measurement--

A Beckman Model 402 flame ionization detector (FID) was used to measure the test gas concentrations at selected locations. Procedures described in EPA Method 25A were followed (see Appendix H). The detector was calibrated with certified mixtures of test gas and air at concentrations of approximately 10, 100 and 1,000 ppm. In addition, the FID response was checked with an NBS traceable mixture of methane in nitrogen and compared to the response with the test gas. This difference in response should be constant at different concentrations and served as a check on the purchased certified gases. Two calibration curves for this instrument were made; one in the 0 to 100 ppm range and one in the zero to 1000 ppm range.

During the LEV evaluations, the FID was zeroed and the calibration checked at the start, half-way through each day's testing, and at the end of

the day's testing. A record of each calibration was kept in the lab note book and on the strip chart recorder. If the calibration changed by more than 5 percent, the instrument was checked according to manufacturer's instructions. The data obtained prior to the calibration check was voided and the tests repeated if this occurred.

Consumables

The main consumable in this work was the test gas difluorochloroethane. It was purchased in pure form in compressed gas cylinders. Hydrogen fuel for the FID was the only other consumable.

Services

No outside services were used.

G.3 DATA GENERATION

Experimental Design

For each test, inlet test gas flow rate, air flow data, exhaust flow data, and test gas concentrations were recorded. All gas and air inlet flows were manually set and recorded at the start of each test with the LEV turned off. Test gas concentration at the breathing zone were monitored with the FID until a steady concentration was observed on the strip chart recorder. A reading at the breathing zone and air concentrations in front and behind the hood were measured for two minutes each. The LEV system was then turned on and the concentration readings repeated. A final concentration reading in the LEV exhaust duct was also made. The LEV system was then turned off and the next test flow condition was set. Ten percent of the test runs were repeated on a random basis to check reproducibility. The data form in Figure G-1 was used to manually record and store raw data.

The most important values measured during each test are the test gas inlet rate and the test gas concentrations since these values most directly effect the LEV system effectiveness calculations. Section 3.4.2 describes LEV efficiency calculations.

Date _____ Test No. _____
 Vent Configuration _____ LEV On _____ Off _____
 Operator _____

Time cfm	Test gas concentration			Flow into drum		LEV exhaust flow	
	Location	Units	ppm	Test gas flow, reading cc/min	Air flow, ΔP , "H ₂ O cfm	ΔP , "H ₂ O	Dia.
	Breathing zone						
	Site 2						
	Site 3						
	In exhaust duct						

Barometric pressure; _____ in. Hg.
 Room air wet bulb/dry bulb temperatures; _____ °F _____ °F; % moisture _____
 Test room air flow; ΔP _____ "H₂O; duct diameter _____ inches; cfm _____
 Test gas rotometer number _____
 Air flow orifice number _____
 LEV exhaust flow duct diameter at pitot tube location _____ inches

NOTES _____

Figure G-1. Data recording form for each test.

Sample Collection

No samples were collected since a continuous monitor was be used to measure gas concentrations.

Sample Custody

No samples or reagents were used. All experimental notes and data were contained in a laboratory notebook. In addition, the strip chart which recorded the FID results were marked with date, time and test conditions, and instrument calibration data.

Laboratory Analysis Procedure

Not applicable.

Internal Quality Control Checks

Zero and span gases were used to check the FID during each test day; at the start, the end, and midway through the day's runs. The zero gas was certified hydrocarbon free nitrogen and the span gases were certified test gas mixtures in air purchased from Matheson in compressed gas cylinders. These certified gases were attached directly to the FID sampling line for calibration purposes.

Performance and System Audits

A single system audit was conducted by PEI's QA staff after the initial shakedown period and prior to obtaining actual test data. One performance audit of the FID was conducted early in the test program by PEI's QA staff.

G.4 DATA PROCESSING

Collection

All flow and concentration data were recorded manually. Test gas concentration data were also recorded on a strip chart. The FID strip chart and manually recorded readings were converted to actual concentration readings by using a calibration chart which relates chart or meter units to ppm by volume.

Validation

A check on measured data was made by comparing the test gas rate in the LEV exhaust duct to the test gas injected into the drum. If the former exceeded the latter (i.e., a LEV effectiveness greater than 100%) some error in flow and/or concentration has occurred and the data are not considered valid. In addition, a mass balance of test gas inflow with test gas outflow in the LEV exhaust and the room exhaust was made.

Storage

Hard copies of the manually collected data from each LEV system evaluation were maintained in a lab notebook. The data form shown in Figure G-1 was used to record all data.

Transfer

No data transfer was performed. Separate calculations were made for each test.

Data Analysis

Very limited data reduction was required since raw test gas concentration values were used directly in the LEV effectiveness calculations as described in Section 3. required.

Air flow data were reduced as follows.

The air velocity in the duct was calculated by:*

$$V = 85.49 \text{ } C_p (\Delta P) \text{ avg. } \frac{T}{P_M}$$

where:

V = air velocity, ft/s

C_p = pitot tube coefficient = 0.99 for standard type pitot tube

ΔP = velocity head, inches of water

T = air temperature, °R

* Industrial Ventilation, American Conference of Governmental Industrial Hygienists, 19th Edition.

P = absolute pressure in duct, in. of Hg. = Pbar $\pm$ gage pressure in duct

M = molecular weight of air = 29.0

The air flow was calculated by

Q = 60 (V) A

Q = actual air flow cubic feet per minute

V = air velocity, ft/s

A = duct cross-sectional area, ft² = $\pi d^2/4$

Two traverses of the duct cross section were made at each of two flow rates to determine the average velocity head (ΔP). If these averages differed by more than 10 percent, additional repetitions were made.

G.5 DATA QUALITY ASSESSMENT

Precision

Three flow measurements and four test gas concentrations were measured during each test. Objectives for the precision, accuracy, and completeness of the major measurement systems used are summarized in Table G-2.

LEV System Exhaust Flow--

A standard type pitot tube was used to measure the velocity head of the air in the duct leading from the LEV to the main exhaust fan using procedures described in EPA Methods 1 and 2.* The velocity head was visually read on an inclined manometer. Initially, the flow through the duct was measured at a number of different flow rates and plotted against the velocity head at the duct center. This center point velocity head was then used to monitor the flow during each test. A mercury in glass thermometer and mercury in glass barometer was used to measure air flow temperature and the barometric pressure. A precision of at least 18 percent was achieved by this method.

Drum Air Inlet Flow--

The air pumped into the drum was measured with an orifice which is calibrated with air and a wet test meter in the range of 0.5 to 2 cfm, and

* 40 CFR, Subpart 60, July 1985.

TABLE G-2. PRECISION, ACCURACY AND COMPLETENESS OF TEST SYSTEMS

Measurement parameter	Measurement method	Calibration device	Expected results, %		Completeness
			Precision	Accuracy	
Gas velocity/volume	Standard 8 type pitot tube and inclined manometer	EPA design specifications and standard pitot tube	$\pm 18^a$	$\pm 10^a$	95
Difluorochloroethane concentration	Beckman Model 402 FID	Certified calibration gas	$\pm 5^b$	$\pm 5^b$	90

^a As listed in EPA QA Handbook for Air Pollution Measurement Systems, Volume III, EPA-600/4-77-027b.

^b Percent of span.

with a dry gas meter in the range of 2 to 4 cfm.* A precision of at least 5 percent is expected with this device.

Test Gas Flow--

The test gas flow rate was measured with a rotameter which is calibrated with pure test gas and a bubble flow meter. Each data point for the calibration curve was measured in triplicate and an average value used. At higher test gas flow rates, the precision will be within 2 percent according to the manufacturer.

Test Gas Concentration--

The Beckman model 402 flame ionization detector was set up and operated in accordance with the manufacturer's specifications. Daily calibrations along with periodic zero and span checks during sample analysis were used to demonstrate that instrument variables are within acceptable limits. If the calibration was off by more than 5 percent, the runs since the previous calibration were voided.

Accuracy

Traceability of Instrumentation--

The FID's Beckman serial number was used to uniquely identify this instrument. Flow measurement devices (rotameter, orifice and pitot tubes) were also identified by their serial numbers.

Maintenance and calibration records for the FID were kept in the laboratory notebook during this study.

Traceability of Standards--

Primary flow measurement instruments such as the standard pitot tube and orifice meters were used. There was no NBS traceable standard for the test gas and PEI checked the certified gas concentration by comparing the FID response at different concentrations to NBS traceable methane in air mixtures. This response difference should be constant at each concentration.

* The wet test meter capacity is 2 cfm.

Traceability of Samples--

Not applicable.

Traceability of Data--

Original data sheets for each test and the FID strip charts were carefully labeled with time, date and test number.

Methodology--

Federal reference methods for measuring flow in ducts (Methods 1 and 2) were used. An FID was used to measure test gas concentration. The FID is the analysis instrument used in EPA Method 25A.

Reference or Spiked Samples--

Not applicable.

Performance Audits--

The FID calibration was checked three times per day. Leak checks of the sampling system were conducted daily.

Representativeness--

This experiment was designed to simulate actual drum filling operations by using a matrix of air flow rates and test gas injection rates. The sample system was designed to collect a representative sample during each matrix condition.

Comparability

Standardized data reporting for each test was accomplished by using the test data form presented in Section G-3. Metric units were used and English units shown as required for clarity.

Completeness

As previously shown in Table G-1, 95 percent of flow data and 90 percent of gas concentration data should be acceptable.

G.6 CORRECTIVE ACTION

PEI conducted an independent systems audit and reviewed this project during the sampling periods. Any problems or inconsistencies were reported to PEI's Project Manager and the EPA Task Manager. Corrective action and modifications were made immediately by PEI. PEI's QA coordinator ensured that the corrective actions were made and produce the desired results.

There were no modifications to the QA plan.

G.7 DOCUMENTATION

After each day's test runs, the data were reduced and LEV effectiveness were calculated as described in Section 3. Air flow and test gas mass flow rate calculations were performed directly on the raw data forms. After the LEV effectiveness data were plotted against test gas inlet rate, any inconsistent results should appear. These calculations were rechecked and the test repeated if necessary.

APPENDIX H

DETERMINATION OF TOTAL
GASEOUS ORGANIC CONCENTRATION

DETERMINATION OF TOTAL GASEOUS ORGANIC CONCENTRATION

H.1 SAMPLING APPARATUS

Sampling and analysis procedures for the test gas followed the procedures described in EPA Method 25A*. The sampling apparatus is shown in Figure H-1. The system was set up and operated in accordance with the guidelines in the operating manual for the total hydrocarbon monitor. In addition to the hydrocarbon analyzer, the sampling system consisted of:

Sample Line - 1/4-in. Teflon lines, about 10 feet long.

Sampling Manifold - A stainless steel 3-way valve and 1/4-in. stainless steel tubing to supply calibration standards and sample gas to the monitor. One three-way valve was used to select between calibration or sample gas. Four separate sampling lines with valves were connected to a manifold on the sampling valve inlet.

Calibration Gases - Certified difluorochloroethane standards in air and zero (<0.1 ppm THC) nitrogen were used to calibrate the monitor.

Fuel and Air - A cylinder of 40 percent hydrogen/60 percent nitrogen and a cylinder of compressed air were used to provide fuel and air for the analyzer's flame.

Chart Recorder - A Heath strip chart recorder was used to provide a permanent record of hydrocarbon concentration data.

The monitor was a Beckman 402 total hydrocarbon flame ionization analyzer. All critical sample-handling components of the analyzer are in a heat-controlled oven. The oven temperature is maintained at 250°F throughout. The following analyzer specifications are provided by the manufacturer:

Full-scale sensitivity: Adjustable from 5 ppm to 10,000 ppm (1%) methane

* 40 CFR, Subpart 60, Reference Method 25A, July 1985.

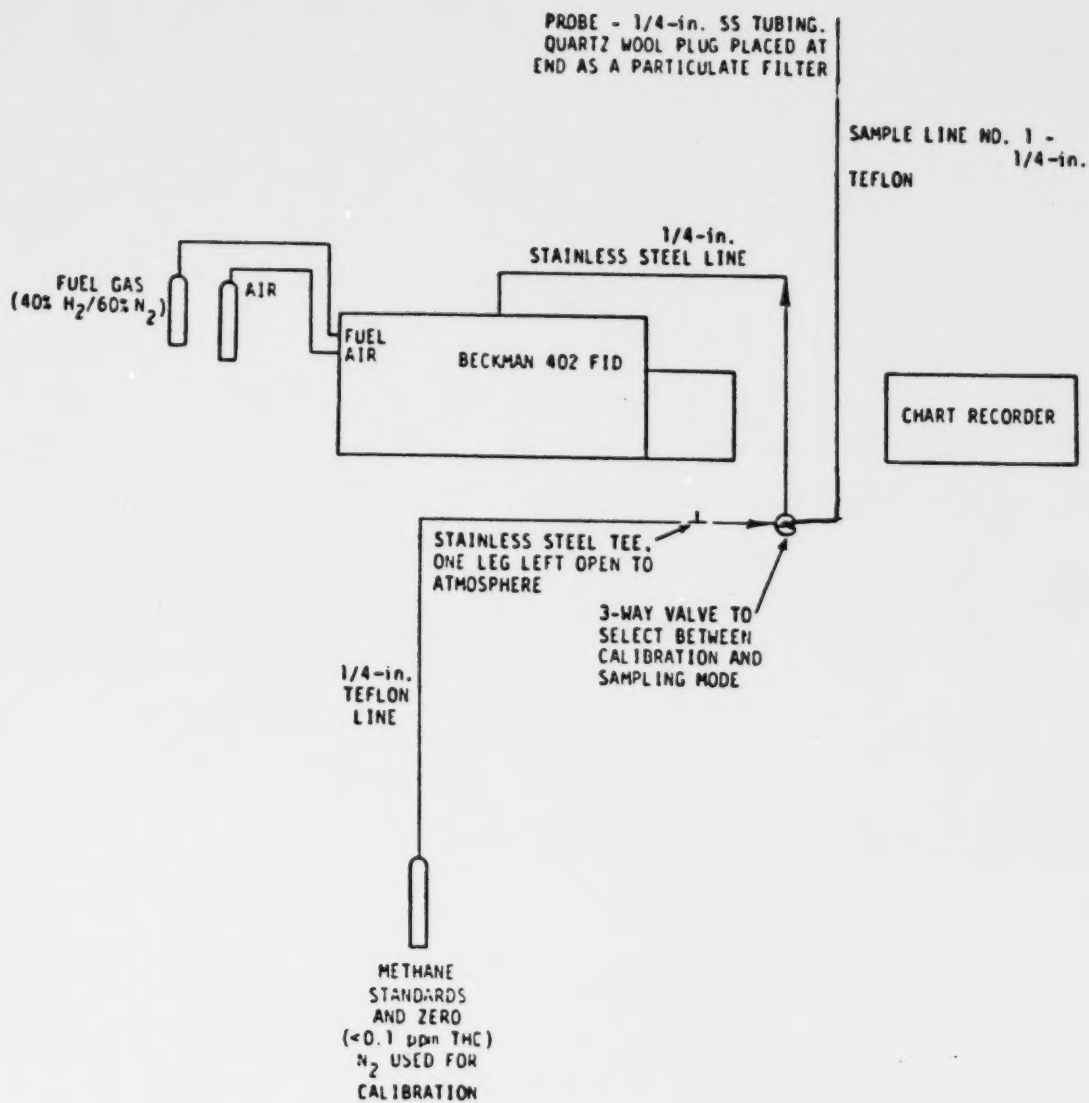


Figure H-1. Method 25A sampling system.

Response time (0 to 90%): <1 sec for oven temperature of 200°F
<1.5 sec for oven temperature of 400°F

Electronic stability: ± 1 percent of full-scale per 24 hours, with
ambient temperature change of less than 10°F

Reproducibility: ± 1 percent of full-scale for successive identical
samples

Output: Selectable from 10 mV, 100 mV, or 1 V.

H.2 SAMPLING PROCEDURES

Zero nitrogen and two certified test gas standards are used to calibrate on each monitor scale. A programmable calculator with a linear regression program is used to calculate the y-intercept, slope, and correlation coefficient for each curve. When the calibration is done, testing is started by adjusting the air and test gas flows into the drum and taking readings of the concentration at the selected sampling points.

A post-test drift check is performed on the monitor midway through the test day. The drift check consists of introducing zero nitrogen and a mid-level test gas standard to the monitor and comparing the response with that obtained during the pretest calibration. Method 25A specifies the calibration drift for each standard must be less than 3 percent of the response for the span gas.

Data reduction was done on site and consisted of recording the monitor response for each sampling period. The average hydrocarbon concentration for the period was calculated from the response and the calibration curve generated prior to the test.

H.3 QUALITY ASSURANCE PROCEDURES

The following procedures are used to assure the production of quality data from the monitor during the test program.

Sample Line Leak Check

Prior to testing, sample line inlets are capped off and the sample flow rotameter on the hydrocarbon monitor is observed. No flow on the rotameter indicated that the sample lines are not leaking.

System Integrity Check

Periodically during the test program, zero nitrogen and a test gas calibration gas standard are sampled through the sample lines. The responses for gases sampled this way are compared with responses for the same gases sent directly to the sampling manifold to verify that samples are not diluted or contaminated by the sampling system.